ELEMENTARY GEOLOGY

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PREFACE

There are already a number of good elementary text-books on Geology, and at first it may seem that there is no special excuse for the appearance of another elementary work. However, it has seemed to me, for some time, that there is need of a Geology in which more stress is placed upon the dynamic aspect of the subject than is commonly given.

It is partly in the hope that this apparent need may be supplied, that this book is prepared. Some may question the wisdom of the very notable curtailment of the stratigraphic side of the subject, but I believe that it agrees with the best educational needs. In this part of geology there is too much abstract fact for the average high school student to be able to profit from the great truths which these facts teach. It is my belief that it is better to state the truths without the introduction of these bodies of fact; for, at best, in an elementary book only part of the facts can be presented. In other words, I believe that the study of stratigraphic geology belongs to higher grades than the secondary school. At the same time the main truths of the subject may properly be presented to the pupils of these schools.

With structural and dynamic geology the case is somewhat different. Here the body of fact necessary for elementary understanding is not so great nor so difficult to grasp. The teachings of these truths of geology are illustrated on every hand, and, in fact, some of them are already familiar to the pupil before he enters upon the study. They deal with phenomena in the midst of which we dwell, and hence should become a part of the mental possessions of every high school pupil. I believe that these aspects are preëminently suited to become a part of the secondary school curriculum.

The second reason for putting forth the book is to furnish a companion and adjunct to my Elementary Physical Geography. Parts of this need explanation and amplification, such as a Geology can give. Moreover, I believe that a year given to the combined study of the two subjects will furnish a training in science which will be of great value. The study of the land, as covered in physical geography of the modern school, needs to be preceded by a knowledge of geology, and it is my hope that the study of this will be introduced into the schools. Really this land study is a part of geology, and hence, though the titles of the books are different, there would be no real break in the treatment if, after a study of air and ocean, geology is taken up, and this be followed by the study of physiography or physiographic geology. In these studies I would urge most strongly the advisability of laboratory and field work, whenever and wherever possible.

In the preparation of this book, I am indebted to my colleagues at Cornell, Professors Harris and Gill, for suggestions and other aid. I have also drawn upon all the available literature, and have endeavored to do so carefully. Mistakes and misinterpretations may have crept in, but I believe that the book is as free from them as could well be expected. For illustrations I have depended largely upon the materials in the geological laboratory of Cornell University, and the majority of these are original. Other illustrations are obtained from various sources, for which acknowledgment is made in the list on the succeeding pages. To those who have kindly allowed me the use of photographs not before published, I return especial thanks. These and the other borrowed illustrations will add greatly to the value of the book. The drawings showing cross-sections of the land, such as Figure 54, have been made by Mr. C. W. Furlong, instructor at Cornell University.

RALPH S. TARR.

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ACKNOWLEDGMENT OF ILLUSTRATIONS

I am indebted to the following sources for the illustrations enumerated. Some of them have been changed to suit the needs of the book. The source of a few of the photographs could not be determined. The great majority of the original photographs are the result of the excellent photographic work of Mr. J. O. Martin, a student at Cornell. The photographs of fossils, and some of the views, were made by Mr. B. F. White of Ithaca.

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ELEMENTARY GEOLOGY

CHAPTER I

INTRODUCTION

THE earth has always furnished an interesting theme for the minds of thinking men. Speculations concerning its origin and history are found in the writings of philosophers and scientists of all times. The ancients pursued the study with considerable success. Then elapsed many ages during which almost no progress was made. A hundred years ago there was hardly more knowledge of the history of the earth than had been possessed by the ancient Greeks.

Within this century, and indeed almost within the last half of it, the science of Geology, or Earth History, has been developed. Even now the story of the earth is but partly known, and in portions of the world; there are bodies of men who are devoting their lives to the fascinating work of reading from the rocks the secrets which are engraved on them. The rocks are the pages

and chapters which, when studied with care, unfold a story of changes and progress throughout ages,— changes which are still in operation.

We may well borrow an illustration from human history. At present we are all contributing our mite toward a record of human progress; and all our ancestors have been doing the same throughout all the time that men have lived upon the earth. The events of the day we can see and understand; those of a century since are known with only partial completeness, and to truly appreciate them the historian must search and study with care; concerning the occurrences of a thousand years ago our information is very fragmentary; and no one knows the actual history of the early members of the human family.

Just so in geology: the changes of to-day can be seen, studied, and understood; but the events of the past become less and less clear as time lengthens, while concerning the earliest chapters of the history we can only conjecture. The researches of a multitude of men have served to give us the main outlines of this earth history; and it is this story that we shall study in a brief way. Many pages will be found missing, just as would be the case if we were studying the records of the ancient Persians; and it will be found that there are many events which are still puzzles, and about which the best we can do is to speculate.

This condition has led many who have given cursory glances at geology, to suppose that it is a science of guesses: it is rather to be looked upon as a fortunate illustration of the fact, that there are some things in creation which the minds of even the best thinkers cannot explain. We are entirely too apt to believe that everything worth knowing about the universe is already understood, and to confound theory with fact. Here in this subject we shall find many things that we do not know; and perhaps some of them will always remain unknown.

The earth's study is a difficult one for the person who would read from nature itself. In such a study we are usually able to see only the merest film of rock at the surface. Here and there the upturned strata of a mountain, or the layers through which a river has cut its gorge, or a mine has pierced, will give us a glimpse of the conditions below. But a mile is the deepest that we have penetrated, and nearly everywhere our studies are confined to the very surface, if, indeed, even this is not forbidden us by a thick soil covering. We can study to a depth of only a mile: then how can we tell what is the condition of the other 7900 miles? Naturally, if we would form an idea concerning these conditions, we must speculate, and some of our theories are confessedly little more than guesses.

While there are certain comparisons which may

fairly be made between geology and human history, there are also striking differences. There was a time — and indeed it continued down to the memory of some geologists still living — when it was believed that the history of the earth had all taken place within a few thousand years. Then great difficulties were encountered in the attempt to reconcile with this preconception, the facts so plainly stamped on the face of the rocks. The only way in which this was possible, lay in supposing that the real earth history had been one of great and frequent catastrophes, and that the ordinary conditions of the present were introduced only after that history had practically ended, and the earth had reached its present form.

Until geologists were driven from this belief by the accumulation of unanswerable facts, there was no real *science* of geology. At the beginning of the book it is impossible to state the *proofs of the immense age* of the earth; but it is hoped that as the pages are turned, this truth may become more and more firmly rooted in the reader's mind. Although as yet no one is ready to say how old the earth is, geologists are united in the belief that its age is to be represented in millions of years; and no one can study geology intelligently who is not ready to grasp this great and fundamental principle.

Geology is so young that some educated people are

not yet ready to take this step; just as in the early days of astronomical science there were those who held to the long-abandoned belief that the stars were set in the firmament, but a short distance above the earth. Now, even the youngest thinker gazes into the starry vault, awed by the grandeur of the fact, that if one of those twinkling bodies had been extinguished a century ago, it would still be visible; because, even with the rapidity of the passage of light, time enough has not yet elapsed to telegraph the fact to the earth.

So the geologist looks at the hill and fully realizes the insignificance of the human mind, when he thinks that this same hill, with nearly the same form, witnessed the coming and going of the red man; that it was still a hill before the human race appeared upon the earth; and that, during all this time, it has been slowly changing, with a life history to be measured in tens or even hundreds of thousands of years.

Astronomers demand that we discard the human conception of distance and think of millions of miles: geologists demand the same for time. Our experience is too limited for us to truly appreciate these conceptions, for a century seems a very long time, and a thousand miles is an immense distance; but if one would come in touch with these two broad sciences, geology and astronomy, he must first enlarge the power of the mind beyond the tiny range which actual experience gives.

While in a measure one may do this by reading and thought, it is best done by an actual study of the earth itself. Something may be learned from the printed page, but geology is most effectively studied out of doors. In chemistry or physics we can read the facts from a text-book; but how much more impressive and important is actual experiment! So in geology: it is the history of the earth as revealed by the rocks, from which every one may decipher a page or two for himself. It is within the power of every teacher to have this done; and on his way to and from school, every student can find a lesson.

The rock by the roadside is crumbling and forming soil; yet our fathers have passed this spot for a quarter or half of a century, and it has remained almost unchanged. This slow action of rock-crumbling has in some places produced a layer of soil many feet in depth, and the time consumed in its production must have been very great. When the snow melts, or the rain falls, the rivulet is swollen to a torrent, and is laden with mud. It is carrying many fragments of soil and rock, and each day it is doing a tiny bit toward the enlargement of the valley which it occupies, and which it has formed; but in the lifetime of the oldest resident, no notable change has occurred. These are some of the lessons to be learned on every hand.

From what is written just above, one can see a second

great principle in geology: that *in the present we have an illustration of what has happened in the past.* In human history we assume that, in general, our ancestors have been guided by the same motives which actuate us. There have always been evil and good, sloth and ambition, weakness and strength, and the other features of mind and body upon which the progress of humanity depends. We know that these rule the world to-day, and that they have been the main factors in past development, as revealed by history; we assume that the same conditions existed before history was recorded. So, while history has been complex, and many different results have been reached, there has always been at work the same set of conditions.

The geologist, at first against his preconceptions, but now freely, sees in the pages of the earth's history, positive proof that the changes which are now slowly operating on the surface of the earth have always been at work, and that the present and past are alike in this respect. This does not mean that nothing has ever been different; but that the processes of nature have remained essentially the same. There have been many complexities, but still in the present we see the conditions of the past. The science of geology is built upon this conception, whose proof is so abundant as to have won full acceptation from all modern workers in the subject.

So the history of the earth has been one of slow changes like those now in operation; but these have been working for such a great length of time that a wonderful series of events has taken place. Since this is so, it follows that the best way to unravel the past, is to appreciate the conditions of the present, and then apply the knowledge thus obtained to a study of the early ages. We will therefore first look at the earth as it is, then as it has been.

It is customary to divide geology into parts, not because there is any real separation, but rather for the convenience of grouping allied phenomena. Geologists differ in what they include under the several divisions, showing that there is no real distinction. In this book the subject will be divided into three parts: (1) *Structural Geology*, which deals with the materials of which the earth is made, without reference to their origin. (2) *Dynamic Geology*, which considers the forces that are at work on the earth to modify its surface, and the changes which these are producing. (3) *Stratigraphic Geology*, which treats of the earth's past and its development since the beginning of the readable history. A fourth division commonly made is *Physiographic Geology*, which treats of the outlines and features of the land, and the history which has produced them. A certain amount of physiographic geology is included under the divisions of dynamic

and stratigraphic geology, but no special consideration is here given to this part of the subject.[1]

[1] The reason for this omission is that I have already treated this subject in my *Elementary Physical Geography*, and those who wish may find it there. It is my hope that the teacher may see fit to depart from the time-honored custom of separating geology from physical geography. It seems to me that an intelligent study of the land demands a knowledge of geology, and therefore that this should precede the physiographic part of physical geography. According to this idea, in cases where a year or more can be given the subject as a whole, the order of study should be: air, ocean, geology, and land form.

CHAPTER II

THE GENERAL FEATURES OF THE EARTH

The Earth a Planet. — The earth is a great spherical body with an equatorial diameter of about 7926 miles, and a circumference of nearly 25,000 miles. It is one of a family of bodies in space, which journey about a central member, the sun. These *planets* all rotate on axes and revolve about the sun, being kept in their places by the action of gravitation, which governs all bodies in the universe.

Each member of this solar family is exerting some influence on the earth; but two, the moon and the sun, are the most important in their effect; the moon because it is so near, and the sun because it is so large and hot. From the sun are obtained the heat and light which render possible the life on the earth; and by far the greater number of geological changes which are in progress upon the surface of the earth, are derived from solar energy.

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Condition of the Earth. — There are three parts to the earth — a *solid* portion, or the earth itself; a *liquid*

part, the ocean; and a *gaseous* envelope, the atmosphere. Each of these is important in the study of geology.

The Atmosphere. — This, which is everywhere present but invisible, surrounds the earth with its life-giving substance, and extends to a height of hundreds of miles from the surface, though at elevations of three or four miles it becomes so thin that breathing is difficult.

The presence of the air is necessary for the existence of animal and plant life. It distributes the heat from the sun; and in it, clouds are formed, from which rain may fall, while by its movement the winds are made to blow. The rain and winds, the heat and cold, and indeed the very air itself, are among the most important of the agents of change with which geology deals.

The air is a mixture of gases. Two of these, *oxygen* and *nitrogen*, are of chief consequence — about 21 % of the former and 79 % of the latter.[1] The really active part of the air is oxygen, for everywhere it is found entering into chemical combinations with many substances. If a piece of coal or wood is burned, the oxygen of the air joins with the carbon, and there is formed a gas, composed of the two elements, and known under the name of carbonic acid gas (carbon dioxide, CO_2). If a tree dies and decays, a similar

[1] We omit consideration here of the recently discovered argon, which so closely resembles nitrogen, and about which, as yet, we know so little.

change takes place much more slowly. So, also, the active oxygen of the air is constantly engaged in the decomposition of the rocks, causing changes which we know as *oxidation*. This action is well illustrated in the rusting of iron.

In the air there is a small amount (about 0.03 %) of *carbonic acid gas*, which the plants use to obtain the carbon needed in their growth. Charged with this rain water becomes a weak acid, of the same kind as soda water, though far weaker. When in this condition, water may dissolve some rocks and minerals, and may cause changes in others.

A small quantity of evaporated water, or *water vapor*, is constantly present in the atmosphere, and under favorable conditions this may be condensed into rain. One of these conditions is the presence of minute solid particles of *dust*, which are everywhere floating in the air. So by this means the rain falls, rivers are formed, and springs appear, while an entire set of important changes is begun.

The atmosphere is a great engine with many functions and many duties to perform, and the heat of the sun is the fuel.

The Ocean. — Covering about three-quarters of the surface of the earth are the oceans, with an area of about 145,000,000 square miles. Near the shores of the continents they are shallow, but in some places,

generally in mid-ocean, the depth is over four miles, while the average ocean depth is more than two. Hence the earth possesses a vast area of salt water, and this is not quiet, but has a slow movement in the form of *ocean currents*. (See p. 234.)

The ocean is also disturbed by two great but very low waves which pass around the earth, causing the waters to rise and fall twice each day, and on the shores producing the phenomenon of *tides*. The tide is mainly caused by the moon, although the sun aids in the formation of the tidal wave.

A more universal movement of the ocean, is one that is confined to the mere surface, and is caused by the wind which blows over it. Everywhere, and always, the ocean surface is disturbed by the *wind wave*, sometimes only a ripple, at other times a billow rising twenty or thirty feet into the air, and stirring the waters to movement at a depth of two or three hundred feet.

The ocean is of the utmost importance in geology; it is the great dumping ground for the waste of the land. The waves beat upon the coast and wear it away, the rivers bear floods of sediment into the sea, and the materials thus obtained are spread out over the ocean floor. However, the ocean, by covering the greater part of the earth's crust with water, protects it from the destructive action of the weather, to which

the dry land is exposed. It also serves to modify climate, and is the home of a great abundance and variety of animal life.

In composition, the ocean contains only three or four per cent of salty impurities, the remainder being pure water. There is a considerable variation in this respect, for off the mouths of rivers the sea-water is freshened, as it is also in regions of heavy rainfall. On the other hand, in warm, dry, enclosed seas, like the Red Sea and the Mediterranean, nearly constant evaporation carries away the fresh water, and makes the remainder more salt.

Usually the waters of the ocean surface are warm, being well above freezing-point, though in the Arctic and Antarctic zones the temperature is always low, and in winter the surface is frozen. Also in the deeper parts of the ocean, the temperature of the water near the bottom is not far above the freezing-point. This is because of a great, slow movement of cold water along the ocean bottom, from the polar regions toward the equator.

The Solid Earth. — *Surface Form.* Wherever a part of the solid earth is exposed above the ocean, it is found to be composed of rock; and this is generally hard rock with a soil covering of greater or less depth. We speak of this as the *earth's crust*, and it is the only portion of the solid earth with which we are familiar from actual examination.

When we study it in detail, the crust of the earth is found to be very irregular. Considered in a large way, it is a sphere, and even the greatest elevations and depressions are tiny in comparison with the mass of the earth itself. The largest irregularity is that which is known as the equatorial protuberance. This depends upon the fact that the earth is not a true sphere, but a spherical body somewhat flattened at the poles (an oblate spheroid), so that the diameter at the equator is 7925.6 miles, and at the poles 7899.1 miles. There is nothing in the general appearance of the earth, as we see it, to tell of this deviation from the sphere; but its existence has been proved by very careful measurements.

The continents and ocean basins constitute a second great set of irregularities. Between the deepest parts of the ocean and the highest portions of the land, there is a difference in elevation of more than ten miles. If the sea-water were removed from the globe, the site of the oceans would be occupied chiefly by broad plains, while the continents would rise as great table-lands from these low, level areas. The slope between these two extensive plains is steep (Figs. 1 and 185).

Both from the ocean floor and from the platform of the land, chains of mountains rise, sometimes extending for thousands of miles, and in places reaching an elevation of more than five miles above the level of the

sea. Associated with these are volcanoes, which are conical peaks, often attaining great height, and sending forth steam and molten rock.

Besides the plains, plateaus, mountains, and volcanoes, there are minor irregularities of hills and valleys; and so, by all these features, the spherical surface of the earth is roughened. The geologist finds that these are still being made: the hills are either growing higher or are being lowered, the valleys are becoming

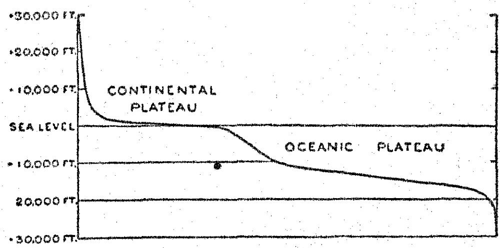

Fig. 1.

Diagram to show the amount of surface at various elevations above and below sea-level.

deeper or more shallow, the volcanoes are building their cones or are losing in elevation, and many mountains are still increasing or suffering loss, while even the continents and oceans are changing their relative positions. This is a world of change, and even that most enduring of features, the rock of the mountain peak, is slowly wearing and wasting away.

Forces Modifying the Surface. Many of these changes are made possible by reason of energy which comes to

us from outside the earth. The tides, caused by the attraction of moon and sun, furnish an illustration of the effects of this energy; and the winds and rains, the alternations of temperature, the waves and currents of the ocean, and many of the other agents which are operating upon the face of the earth, are other illustrations.

But there is another class of changes which cannot be traced outside of the earth. Why do volcanoes cast out rock, ash, and lava; and why are mountains rising and the continents changing in elevation? These features are surely to be traced to some condition *within* the earth; and we believe that, in some way, they are dependent upon great stores of heat which exist beneath the surface.

It was formerly thought that the earth consisted of a rind or crust of slight thickness, and that within this, there was a fiery, molten sphere. Astronomers and physicists have assured us that such a condition is impossible, and that the earth thoughout its mass is as rigid as steel. The proof of this seems convincing, and is accepted by most geologists, although the word *crust*, now with a different sense, is still used in speaking of the outer portion of the earth.

In many places, however, volcanoes bring molten rock to the surface from a considerable depth; and everywhere on the globe, where deep mines and wells have

pierced into the crust, it has been found that the temperature increases as the depth becomes greater. There is much variability, but everywhere this is true, and the average rate of increase is *one degree for every fifty or sixty feet of descent.* In one valuable gold and silver mine, the temperature became so high that it was necessary to abandon it.

If this rate of increase in temperature continues, the interior of the earth must be intensely hot; and, in proceeding below the crust, a region must soon be reached where the temperature is high enough to melt the rocks. But great pressure *raises* the melting-point. That part of the earth which lies deep beneath the crust, is weighted down with a tremendous load of upper rocks, with a pressure perhaps equal to hundreds or thousands of tons to the square inch. Therefore, under this pressure, their melting-point is raised to a point higher than is necessary to melt them at the surface. So it is believed that while the heat is extreme, the deep-lying rocks are prevented from melting by the pressure of the crust.

There seems to be sufficient reason for the belief that the earth is hot within, and, like the sun, continually cooling. Loss of heat necessarily means a loss of bulk or shrinkage on the part of the rocks which are cooling, and it is thought that this contraction causes the constant movement of the crust seen in

mountain formation. Where fissures reach down into this heated mass of the interior, volcanoes may be formed.

Thus we have two sets of forces acting on the earth: changes originating outside of the earth itself and tending to lessen the irregularities, and those from within the earth, which are building them up. These are in opposition, and the form of the land as we know it, is a resultant of their interaction. So far the elevating forces from within have exceeded the destructive agents; otherwise the land would have been worn down nearly to sea-level, while the waste would have been strewn over the bottom of the sea.

CHAPTER III

IMPORTANT ELEMENTS AND MINERALS OF THE EARTH'S CRUST [1]

Common Elements

Characteristics of Elements. — When chemists carefully study a substance, such as a mineral or other organic or inorganic material, they find it to be composed of elements, sometimes several combined, sometimes one alone. These so-called *elements* are the ultimate form to which science has been able to reduce

[1] No attempt is made to treat mineralogy and lithology, but merely to bring out some important points in the relation of minerals and rocks to geology.

At this place it would be well, if possible, to introduce laboratory study of the minerals and the rocks; for nothing can be more difficult, unintelligible, and dull than the study of minerals and rocks from books; but by an examination of specimens, the student is generally interested and instructed. Every teacher can find a few rocks and minerals, either in a gravel bank or a stone quarry; and, for a few dollars, sets of minerals and rocks can be purchased from either H. A. Ward, Rochester, N. Y., E. E. Howell, 612 17th Street, N. W., Washington, D. C., Dr. A. E. Foote, Philadelphia, Pa., or other dealers.

For the short study which is all that most classes would be able to give to this subject, a text-book of mineralogy or lithology is not necessary. The teacher can find the information needed in the books to which reference is made near the end of this book.

matter. Gold is an element, and no skill has been able to simplify it further; nor has any one succeeded in making this substance by any combination. On the other hand, water can be separated into two parts, oxygen and hydrogen, each of which is a gas and an element incapable of further reduction; and not only may these two gases be produced from water, but they can be made to combine and form water.

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So far, chemists have detected about seventy elements in the earth's crust, and there are probably others not yet found. While there are about seventy elements now known, the great majority of them are so rare that they may be neglected in an elementary study of geology. Fourteen are of decided importance, and nearly the entire earth's crust is composed of combinations of these. Named approximately in the order of their consequence, these are: oxygen, silicon, aluminum, iron, calcium, magnesium, potassium, sodium, carbon, hydrogen, phosphorus, sulphur, chlorine, and manganese. To these might be added nitrogen, which, though not conspicuous in the rocks, is an element of prime importance in the air, of which it forms nearly 79%, as an inert, tasteless, and invisible gas.

The elements are variable in habit. Many are *metals*, like iron and gold; some are *non-metallic*, like sulphur; others are *solids*, like iron, gold, and sulphur; and a few are *liquid* or *gaseous*, like mercury and oxygen.

Of the gases, some are invisible like the oxygen and nitrogen of the air, which we are constantly breathing, while others, like chlorine, have distinct color and odor.

There is also a difference in their behavior: gold may be placed in the air, and indeed subjected to almost any conditions, and never change; silver tarnishes when sulphur and some other elements reach it; iron rusts so readily, that in such structures as are exposed to the weather, it is commonly necessary to protect it with paint to exclude the oxygen. If a bar of steel is allowed to remain out of doors, it is first covered with a reddish or yellowish-brown rust, and finally becomes so weak that it crumbles.

Since nearly all the elements are ready to form combinations with others, we need not examine the earth's crust with the expectation of finding many elements uncombined. Very rarely, indeed, pure gold or silver, or some other element, is found in limited quantities; but the law of change and combination is so strong, and is so constantly operating throughout the earth's crust, that the elements are usually combined one with another.

How these combinations take place, the laws which they obey, and the results which are obtained, concern the mineralogist and must be omitted here. The point of importance to us is, that these changes are taking

place, and that throughout nature there is a tendency to change. Old combinations are breaking up and new ones being made. The earth's crust is, in fact, a great chemical laboratory, where innumerable and important reactions are always in progress.

In the air we find the only common, uncombined elements at the surface. One of these, nitrogen, is so inert that it does not readily enter into combination in the crust; but the other, oxygen, is always doing so, and among the rocks there are vast quantities of this element, that have come out of the air to form mineral compounds. This change is occurring even at the present time.

Let us briefly examine some of the chief elements with especial reference to their importance in geology.

Oxygen (O). — By far the most abundant and important is oxygen, which is the great active element of the earth. Not only does it exist in the atmosphere, but, carried by spring water, it enters the crevices of the rocks and passes down into the crust.

When decay, either of mineral or organic materials, is in progress, oxygen is at hand to aid in the work. When conditions favoring combustion are present, it is oxygen that is necessary to promote the change. So aggressive is this element that it has entered into all known parts of the earth; and by the process of oxidation it is still engaged in extending its range.

The great majority of minerals contain this active element, and 47 % of the solid crust is oxygen; it is one of the two substances which compose water, forming nearly 86% of the ocean; it forms 21% of the atmosphere; and animals and plants contain stores of it in their tissues. The fact that there is so much oxygen in the crust of the earth, points to the conclusion that in the early geological ages there was much more of this gas in the air than now; and although some of it is constantly being given back to the atmosphere, it is more than probable that each year witnesses a slight decrease in the percentage of oxygen in the air. Perhaps the time may come when there will not be enough of this precious gas to support the life of the globe.

Silicon (Si). — In the earth's crust the element silicon is never found uncombined; but it is known to chemists as a dull brown powder. In importance it ranks second to oxygen, which is its constant companion. Twenty-seven per cent of the crust is made of this element, so that 74 % of the substance of the known rocks is oxygen and silicon. Its simplest combination is the oxide, *silica* (SiO_2), which is so common as rock crystal or *quartz* (p. 37) and as grains of sand. Besides this simple combination, there are others which to the mineralogist are known as the *silicates*. In these the silicon and oxygen are combined with other elements (see Feldspar, p. 40).

In one or another of these forms, in company with water, silicon finds its way into nearly all the rocks of the earth. In some, like the sandstones, it constitutes a large part of the rock; while in others, such as coal, it is present only in minute quantities — the ash of the coal being in part a compound of silicon.

Aluminum (Al). — This is a metallic element which was a chemical curiosity forty years ago, but is now in somewhat common use as a light, silver-white metal. Like silicon, it combines with oxygen, forming an oxide, *alumina* (Al_2O_3), which we know as the gem sapphire. Aluminum is most common in the earth in combination with both oxygen and silicon, forming a great group of minerals, the *silicates of alumina* (see Feldspar, p. 40). Nearly 8% of the crust is aluminum.

These three common elements, oxygen, silicon, and aluminum, constitute the bulk of our clay and soil, and indeed of the rocks themselves. More than four-fifths of the crust is made of these substances; and when combined with other elements, they form a great variety of minerals, numbering many hundreds. The other elements are relatively uncommon, though they enter into the composition of many important minerals.

Iron (Fe) and Manganese (Mn). — Iron, with which we are so familiar, is rarely found as a free element in nature. Usually it is combined with oxygen; and,

although widely disseminated throughout the rocks, it is not so truly common as are oxygen and silicon. Still it is almost constantly present, as is shown by the yellow and red colors of the soils and rocks, which are tinted by some one of the oxides of iron. Owing to its distinguishing colors, it seems more abundant than it really is. It forms about 5% of the rocks of the surface.

Manganese resembles iron in many respects, and occurs with it in the same combination of elements. It is much less common than iron but is still widely disseminated, and its presence is often shown by the black or purple stains on the surface of rocks. It forms only .08% of the rocks.

Calcium (Ca). — Calcium, a light yellowish metal, is another element that is never found uncombined in the earth. United with carbonic acid gas (CO_2) (and another molecule of oxygen), calcium forms a very common mineral, known as *calcite* ($CaCO_3$) (p. 42), which is present in the marbles used for decoration and monuments. Limestone also is mostly made of this carbonate of lime.

Being slightly soluble, this mineral is almost everywhere present in the water that flows over the land, as well as that which forms the sea. So animals are able to take it from the water and build it into their skeletons. All the shells of ocean mollusks, and the

reef-building corals, are chiefly made of this substance.

Combined with sulphur and oxygen, calcium forms another common mineral, *gypsum* ($CaSO_4 + 2\ H_2O$) (p. 49). Besides this, the element enters into many of the complex silicates, so that we find it as a common constituent of many rocks. Nearly 4 % of the crust is calcium.

Magnesium (Mg), Potassium (K), and Sodium (Na). — Magnesium, potassium, and sodium never exist in a free state, but when obtained by artificial means they are found to be metals. They enter into the composition of many silicates, but are less abundant than the preceding elements, each one forming about 2.5% of the crust. Combined with chlorine, thus forming *chlorides*, each of these elements produces a soluble salt, which is present in nearly all waters, but is particularly noticeable in sea-water. By far the most abundant of these is the *common salt* (pp. 32 and 50) of the ocean, sodium chloride (NaCl).

Carbon (C). — Carbon exists in the pure state in the form of diamond, and graphite or the black lead of pencils; but its most common condition is in combination with oxygen. It is present in the tissue of every animal and plant, and when they decay or burn, the oxygen of the air combines with the carbon to form the important *carbonic acid gas* (CO_2), (p. 118).

This gas combines with other substances to form the group of *carbonates*, of which *calcite* (pp. 29 and 42) is a typical example. While present in many rocks, the greater part of the carbon of the crust appears to have been placed there by the life and death of animals or plants, which have taken the carbonic acid gas from the air, or the carbonate of lime from the water. It is estimated that the percentage of this element in the crust is only .22 % of the whole.[1]

Hydrogen (**H**).—Hydrogen is one of the two elements which constitute water, and in this form it is everywhere present in the crust. Many minerals enter into combinations with water, and as a result of this, the group of *hydrous minerals* is formed. The quantity of water present in the rocks in chemical combination, or held mechanically in the crevices, is equal to many times the bulk of all the water in the oceans.

Hydrogen, combined with carbon, produces the great group called the *hydrocarbons*. These are present in many of the rocks which contain animal or plant remains, but they are particularly noticeable when they form extensive accumulations of natural gas or petroleum (p. 418). Combined with the minerals, hydrogen forms only .21 % of the crust; but, including that

[1] Titanium, always supposed to be a rare element, is found by analysis to be even more abundant than carbon. It is not conspicuous, and hence its importance has long been underestimated.

which is in the air and water, the importance of the element is greatly increased.

Phosphorus (**P**). — Phosphorus is also rare, forming but .1% of the crust. With oxygen it enters into a group of minerals, the *phosphates*, of which the phosphate of lime (apatite) is the most common. That this element is frequently present, though in minute quantities, is shown by the fact that it enters into the bones of animals, and the tissues of many animals and plants; indeed, it is so important, that when man, by careless tillage, has drained the soils of the natural phosphates, some plants will not produce good crops until the need of the phosphate is artificially supplied.

Sulphur (**S**). — This element occurs near volcanoes, and elsewhere, as a pale yellow substance. It combines with many elements to form *sulphides* (see Pyrite, p. 49), or with oxygen (see Gypsum, p. 49), and a metal to form *sulphates;* and if one will burn a sulphur match in contact with a silver coin, he will bring about such a change, tarnishing the coin. Sulphur is found in the tissues of many animals and plants, and is scattered throughout the rocks, of which it forms about .03%.

Chlorine (**Cl**). — This nearly transparent gas, with a greenish-yellow color, and a strong, irritating odor, is present mainly in the combination known as the *chloride*, of which common *salt* (pp. 30 and 50) is the

best and most familiar example. Chlorine forms only .01% of the crust, but is important in the ocean, of which it forms about 2%.

Common Minerals of the Earth's Crust

General Statement. — When they unite, the elements follow definite laws and produce definite results. They build themselves together in regular proportions, forming molecules, and if free to act under favorable conditions, these often construct a regular geometrical form, or a *crystal*. These combinations produce *minerals*, which may be defined as *homogeneous solids*[1] *of definite chemical composition, occurring in nature, but not of apparent organic origin.*

A mineral may be composed of a single element, such as gold, copper, or silver; or, as is very common, it may be made of two or more elements chemically combined. These may be only lightly bound together, as in the case of cinnabar (the sulphide of mercury), where a slight heat serves to drive the elements apart; or they may be so firmly joined, and their chemical affinity so strong, that, like silica, they will resist almost any effort to separate them. What the cause of this affinity is we do not know, but it is the operation of a powerful law of nature.

[1] The single exception is mercury, which is liquid instead of solid.

D

So we find some minerals enduring, and others unstable. Therefore, while the chemical composition is definite, it is subject to change whenever the conditions are favorable. By these changes, rocks are often made to crumble and decay (see Chapter VI.).

Another feature of importance among the minerals, is the difference in hardness. Some, like graphite, or black lead, are so soft that they will mark paper, while others, like quartz and diamond, are harder than glass. Moreover, some are brittle, and others plastic. So there is great variety in minerals, and upon these differences many geological changes depend.

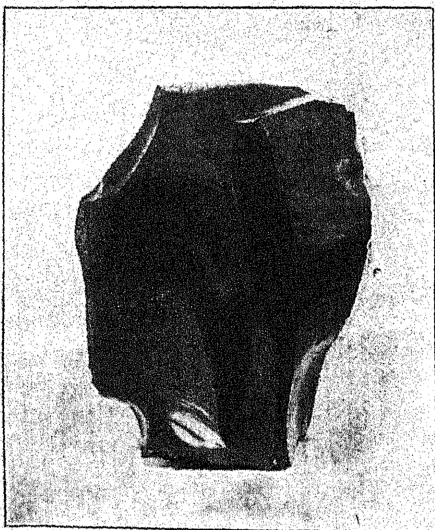

FIG. 2.
Semi-opal, an amorphous mineral.

Although the great majority of minerals are *crystalline* (Fig. 4), some are not built up in definite forms, but take irregular shapes. These are then said to be *amorphous* (Fig. 2). If we allow a solution of salt to

slowly evaporate, distinct cubes begin to form; and as they grow in size, they still remain cubes. These are *crystals*[1] (Figs. 3, 5, 6, and 10), a crystal being a chemically homogeneous solid, bounded by plane faces,

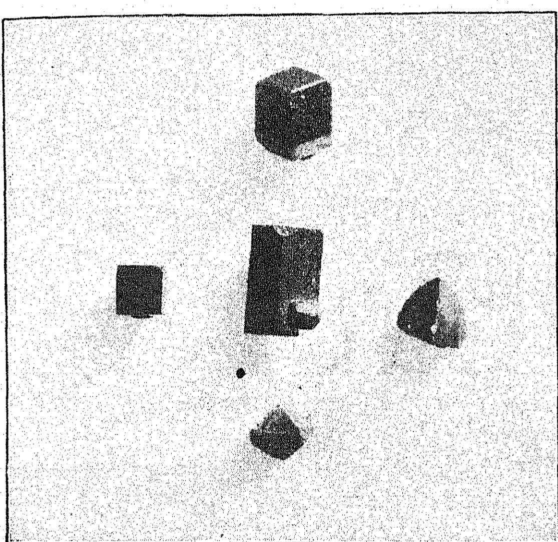

FIG. 3.

A group of five perfect crystals. Upper one, garnet; middle, staurolite; lower, zircon; left hand, iron pyrite; right hand, chalcopyrite.

which make certain definite angles with each other, depending on the peculiar internal structure of the substance.

Usually minerals form under conditions, such as a

[1] Crystals are also formed by chemical change in many substances which are not technically minerals, but are artificially produced. However, the laws operating, and the results reached, are the same in both cases.

lack of room for development, which will not allow the evolution of perfect form. Hence the perfect crystal is rare; but while under these conditions the *boundaries* cannot be present, the internal structure is that of the crystal, and the mineral is truly *crystalline* (Fig. 4). That is to say, the molecules of the elements unite according to the regular laws producing the *crystal structure*, but cannot attain perfect form because the conditions will not permit. It is as if we planted two trees, one in the open air, the other in an insufficient space: the one would be erect and perfect, the other irregular and contracted, but each would have the structure of a tree. So, while the crystal is one of the most interesting and beautiful things in nature, and is of importance to the mineralogist, it concerns the geologist so little that in this book we may disregard it.

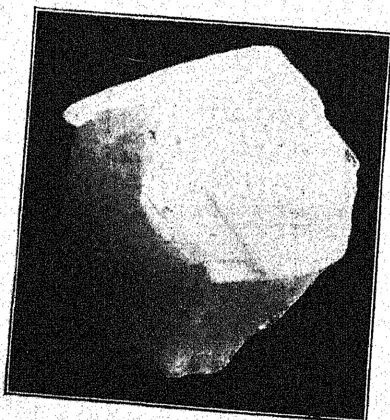

FIG. 4.
Calcite, a crystalline mineral without crystal form. Cleavage faces shown.

In our elementary study of the earth, we must confine ourselves, also, to only the most important of the

minerals. While the mineralogist knows more than two thousand different kinds, we may omit them all, excepting the following nine minerals and groups of minerals. Many of those that are omitted are very rare, and most would never be seen by the average person; but some are of greater consequence, and the teacher may deem it worth while to take up their study as time permits.[1]

Named approximately in the order of their importance, the decidedly common minerals are: (1) quartz; (2) the group of feldspars; (3) the group including calcite, dolomite, and siderite; (4) the group of micas; (5) the amphibole group; (6) the pyroxene group; (7) the group of iron minerals; (8) gypsum; (9) salt; (10) ice and its liquid form, water. The bulk of the earth's crust is made up of these minerals.

Quartz (silica, SiO_2) is the most abundant mineral in the crust of the earth. In color, it varies from a transparent rock crystal, as clear and pure as plate glass, to a jet-black, glassy mass. There are also blue, purple, pink, and other colors of quartz. Sometimes

[1] At this point it is hoped that the teacher may see his way to the introduction of a study of elementary mineralogy, and perhaps to a laboratory study of thirty or forty of the most common minerals, so that the student may really understand what minerals are, how they vary, and how they may be distinguished. Such a study should be introduced from the point of view of mineralogy, and each student should study the hardness, color, cleavage, specific gravity, crystal form, etc., of each species. Directions for such study will be found in any good book on mineralogy. (See also p. 23.)

it is amorphous, but usually crystalline, and very often is found in perfect crystals, — six-sided prisms, terminating in six-sided pyramids (Fig. 5). Among the varieties are agate, amethyst, jasper, etc.

Quartz is light in weight and very hard, so hard indeed that it cannot be scratched with a knife, but will cut glass. It is brittle, and when it breaks, has a rough fracture like that of broken glass, this being known as the *conchoidal* or *shelly fracture*. Being hard, it is, of common minerals, the most resistant to mechanical wear. It is also chemically strong or difficult to change; and silica once formed, remains as silica throughout all the changes to which rocks are ordinarily subjected.

Quartz is slightly soluble in percolating water which bears alkaline substances; and therefore many plants are able to build it into their skeletons by absorbing it from the soil-water, and carrying it upward through their roots. The saw-like edges of some of the grasses and sedges, which cut the hand when drawn over them, are studded with particles of silica thus derived. There are also water plants, the Diatoms, and water animals, particularly certain Infusoria and sponges, which build skeletons of silica taken from the water.

Because of its hardness and chemical strength, quartz may give great durability to a rock. There is no common mineral which resists destruction so well. This

mineral is found nearly everywhere on the surface of the earth, but it is particularly abundant in granitic

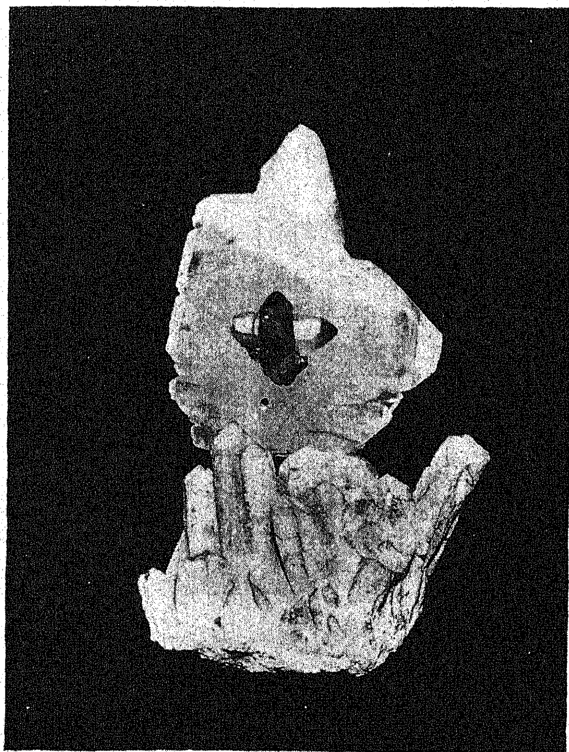

FIG. 5.
A group of quartz crystals.

rocks, sandstone, and the great majority of soils. Wherever found, it is fresh, pure silica, and in this it differs from many of the common minerals which are

so liable to decay. Besides being present in the rocks, it is always found in small percentage dissolved in the waters of lakes, oceans, springs, and rivers.

The Feldspar Group. — Under the name *feldspar*, is included a great variety of substances which resemble one another in some respects, but present enough points of difference to enable the mineralogist to distinguish them. They are all *silicates of alumina* (SiO_2 and Al_2O_3) with some other elements, such as magnesium, potassium, calcium, etc. Each species differs slightly from the others in chemical composition and mineral form. The two most common divisions are orthoclase and plagioclase, which in the ordinary rock specimen, cannot be told apart by the eye alone.

Like quartz, feldspar is variable in color, and light in weight. It is only a little less hard than this mineral; but, while quartz always breaks with irregular face, feldspar, when broken, is found to split in some directions with perfectly smooth faces. This is *cleavage*, and the planes of breakage are known as *cleavage planes* (Fig. 4). The cleavage of feldspar, which is always present, is a part of its habit of crystallization; for feldspar is always crystalline, though good crystals are not common.

To the geologist there are two very important ways in which feldspar differs from quartz: (1) It is not even so soluble as the nearly insoluble quartz; but

(2) when exposed to the weather it begins to change and crumble. A set of complex reactions commences, and in time the feldspar changes from the clear, hard, glassy mineral, to a dull, opaque substance, which can be scratched with a knife; and finally the change results in the production of a powdery, white clay, known as *kaolin*, from which some chinaware is made.

If the chemist should analyze this clay, it would be found to vary considerably from the fresh mineral from which it was derived. Some of the original sodium or calcium, or potassium, has gone away, having entered into combination with other elements, producing a soluble salt which could be removed by solution in water. It would also be found that a considerable percentage of water had been added to the clayey particles. So by chemical process, the form, texture, and the very composition have been changed. Therefore, when exposed to the weather, rocks which contain this mineral, decay and crumble, just as truly as a tree does after it dies and falls to the ground.

We find feldspar, or its decayed products, nearly everywhere. Almost all the lavas that come from volcanoes, and the various forms of granitic rocks, bear one of the kinds of feldspar; and the clay of the soil, as well as of many fine-grained rocks, is in large part made of kaolin, while the waters of the globe

carry in solution many salts which have been formed by the decay of feldspar.

The Calcite Group. — Calcite (Figs. 4 and 6), carbonate of lime ($CaCO_3$), though commonly white, may be of any color. It crystallizes in various forms (such

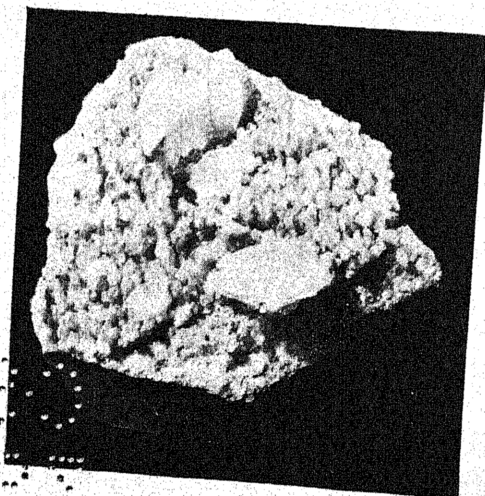

Fig. 6.
A group of calcite crystals.

as rhombs, dog-tooth crystals, etc.), but although usually crystalline, it is frequently amorphous. The mineral is so soft that the knife easily scratches it. It is light in weight, and, when it breaks, cleaves (Fig. 4) readily in two or three directions. Indeed, in the crystals of calcite, the cleavage planes may be seen cutting the mineral into rhombic blocks.

One may easily tell calcite from any other common mineral, by placing upon it a drop of hydrochloric acid, when there is a boiling of effervescent gas, produced by the reaction between the calcite and the acid, which liberates carbonic acid gas.

Carbonate of lime, the main constituent of limestone, is one of the most abundant of rock-forming materials. It is present in nearly all waters on or in the earth, for it is constantly being formed by the destruction of minerals which contain calcium. Its abundance in the water makes it possible for many animals and some plants (corals, shell-fishes, some seaweeds, etc.) to take it from solution and build it into their skeletons; and they do this so commonly that great beds of limestone are deposited in the sea by the accumulation of the remains of these organisms. While carbonate of lime is abundant in many rocks, and especially in limestone and marble, well-defined calcite is not a common mineral. Being soft, capable of ready decomposition in contact with weak acids, and soluble in the water of the crust, this mineral is both mechanically and chemically weak, and hence the rocks made of it do not resist the weather well.

In connection with calcite, we may consider one of the least common minerals, *dolomite* ($(CaMg)CO_3$), which is chemically like calcite, excepting that it also contains some magnesium. In most respects it resembles cal-

cite, but is somewhat more resistant, and is not made to effervesce by cold acid, although warm acids cause this phenomenon. It forms great beds of magnesian or dolomitic limestone, in which it is closely associated with calcite.

Another form resembling calcite is the carbonate of iron, *siderite* ($FeCO_3$), which, in some cases, seems to be

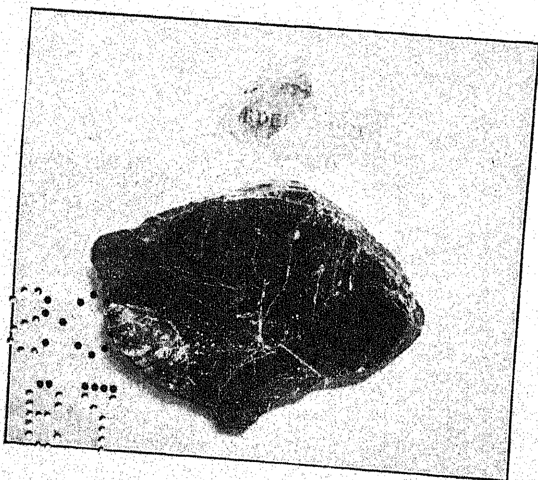

FIG. 7.
Black mica. A thin cleavage piece above, is so transparent that printing beneath it may be read.

calcite, whose calcium has been replaced by iron. It is commonly a brownish mineral, looking like calcite, though somewhat heavier; and, although found in veins that can be worked for iron, it is not one of the important minerals of the crust.

The Mica Group. — In these minerals, of which there are numerous species, depending upon differences in chemical composition, the one characteristic feature is the cleavage. This is so remarkably developed that the mineral splits readily into very thin, elastic plates (Fig. 7). The micas are all silicates of alumina, varying in color, usually from light brown to deep black; and they are all so soft, that they are easily scratched with a knife, and sometimes even with the fingernail.

Like the other complex silicates of alumina (for, in addition to silicon, oxygen, and aluminum, these contain such elements as potassium, magnesium, iron, etc., in percentages varying among the different species), the micas usually decay easily, forming soluble and insoluble products, the former passing off in the water, the latter often remaining, usually as clayey remnants. Some micas are not so easily decayed as many of the rock-forming minerals, and so in the soil, on the beach, and in the beds which have been made by the decay of other rocks, we often find little glittering particles of mica.

This mineral is common in lavas, granites, and many other rocks; and either the fresh mica or its decayed product enters into the soil, while the soluble salts formed from its decay pass into the waters of the earth.

The Amphibole and Pyroxene Groups. — While possessing distinct chemical and crystalline characteristics by which they can be distinguished in the crystal, or determined with the microscope, the minerals of these two groups have so many resemblances, that without a careful study, they cannot be told apart when occurring as small bits in the rocks.[1]

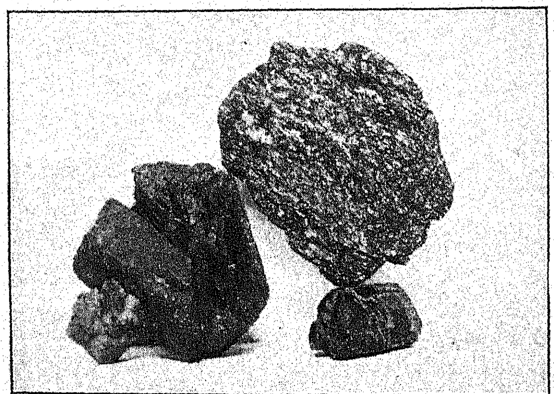

FIG. 8.

Hornblende, on the right side, and augite, on the left.

Of the amphibole group the common representative is *hornblende;* of the pyroxene the common form is

[1] The teacher will, of course, understand that this does not apply to specimens of the mineral collection, which are carefully selected; but the geologist, handling the common rocks, deals with minerals in their usual condition, which is that of small size. In the great majority of these cases, the mineralogist will not find the distinguishing features unless he applies the microscope. So, although quite different, for our purpose they can be grouped together.

augite (Fig. 8). These occur in many of the lavas and granitic rocks, and when so found, are commonly dark colored; indeed, they are often jet-black grains. Chemically they are complex silicates, in which iron is often present. They decay with ease, frequently forming reddish or yellowish stains of iron rust, as the iron molecules combine to form iron oxide. The decayed products of these minerals are common in the clays, and much of the iron coloring-matter of the soil is formed by their disintegration.

Ores of Iron. — Besides the carbonate of iron (siderite, p. 44), there are several oxides of iron and the sulphide (iron pyrites) which are common in the earth.

Wherever any of the iron-bearing minerals (such as hornblende) decay, an oxide of iron is one of the results. The abundance of these oxides is attested by the red and yellow colors of soils and rocks. Many springs bring a form of iron oxide to the surface, where it is deposited from solution as a soft, yellow, iron rust. Iron ores also occur in nearly all the rocks, and sometimes in distinct beds, or veins, which are worked as a source of iron.

Of the iron ores the oxides are the most common. *Magnetite* (Fe_3O_4), a black mineral, usually crystalline and heavy, is present in many of the volcanic rocks, as well as in ore beds and elsewhere. When it rusts

it forms one of the other oxides, *hematite* (Fe_2O_3) (Fig. 9). This is among the commonest of iron ores, being found in many parts of the world, in beds, as well as in the form of a red coloring-matter in the rocks. It also is heavy, and when it rusts forms the yellow mineral *limonite* ($2\ Fe_2O_3\ 3\ H_2O$).

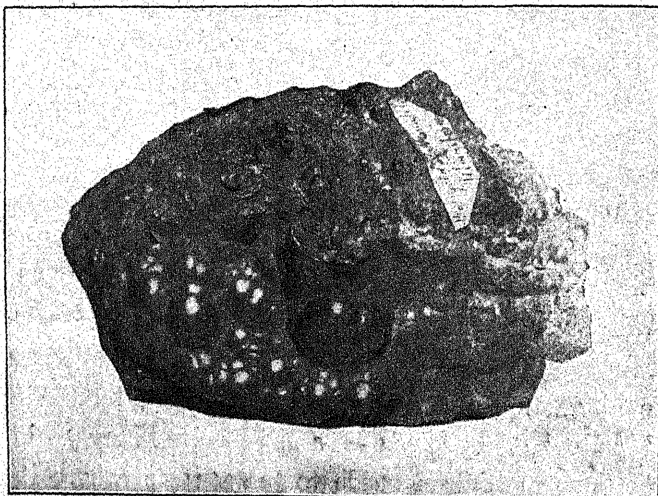

FIG. 9.
Hematite. Botryoidal surface in lower part.

An easy way of distinguishing the three oxides of iron, is by the *streak*, which is obtained by scratching the mineral upon a hard white substance, such as white quartz or rough porcelain. Limonite makes a yellow streak, hematite a red or brown mark, and magnetite a black streak.

The sulphide of iron, *pyrites* (FeS_2), is not used as an ore, but is found in many of the rocks in the form of cubical (or other) crystals (Fig. 10), of a bronze yellow color, being commonly known as "fool's gold."

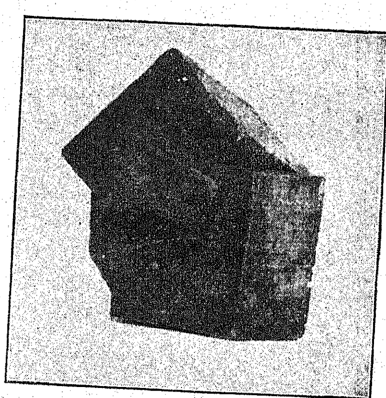

Fig. 10.
Cubes of iron pyrite intergrown.

Gypsum ($CaSO_4 + 2\,H_2O$). — This, the sulphate of lime, is produced by the decay of many lime-bearing minerals, or by the alteration of the carbonate of lime to the sulphate. It is soluble in water and makes it hard. In appearance, gypsum bears a certain resemblance to calcite, but it is softer, does not effervesce with acid, and has a cleavage nearly as perfect as

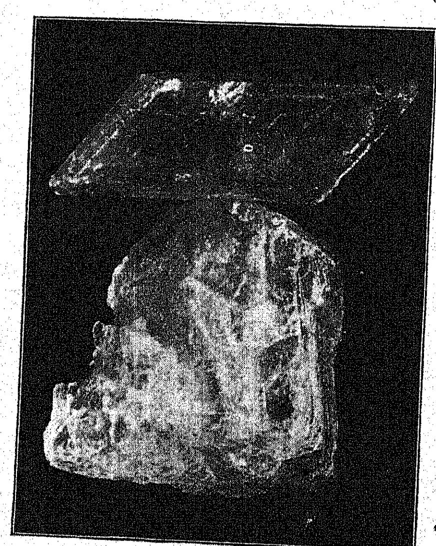

Fig. 11.
Crystal and massive piece of gypsum. Both nearly transparent.

is the solid form of water. The liquid form, or water, is present in all rocks, both chemically combined, and passing freely through them. While quarries and mines show that water is constantly present among the crevices, a careful study reveals the fact that it also exists between the pores of even the densest rocks. It is found in the air as a vapor, from which it descends to the earth as rain or snow, either remaining, flowing away, entering the earth, or passing back to vapor. In the ocean there are about 300,000,000 cubic miles of water.

This substance is commonly either a vapor or a liquid; but in the winter it may become a solid with crystalline habit, and in some of the arctic lands, and on high mountain tops, the solid form is always present. Not only does it exist in great masses in the form of glaciers, but, in some of the colder regions, the soils are permanently frozen to a depth of several hundred feet. While water is very important in these conditions, it also plays a notable part in the changes within the crust, through which it is always moving, dissolving here and depositing there. It is the chief agent by means of which the operations within nature's grand chemical laboratory, the earth's crust, are carried on; and we shall have frequent occasion to note its importance in geological action.

CHAPTER IV

THE IGNEOUS OR ERUPTIVE ROCKS

Definition of a Rock. — A rock is an accumulation of minerals forming a part of the earth's crust. Usually several minerals are thus combined, though in some cases one alone forms the rock. We ordinarily think of a rock as something hard and durable; but this is not necessarily so, for in many cases there is no line that can be drawn between the loose mineral fragments, and the solid rock. A great many of the strata of the earth have been solidified from the loose and friable clays or sand; and in many places this solidification is in progress at the present time (Fig. 12).

On the Florida coast, in the Bermudas, and indeed commonly where lime-secreting animals thrive, the coral fragments that have recently been thrown above the sea-level by the waves, are cemented into a rock that can be used for building; and in such places the houses are constructed of this *coquina* (Fig. 30). Also, in many gravel banks, there are hard cemented layers, side by side with sand and gravel, that men are carting

away (Fig. 13). Water percolating through the layers, deposits a cement of lime or iron, which binds the fragments firmly together; and so the geologist can draw no line between unconsolidated and solidified rock.

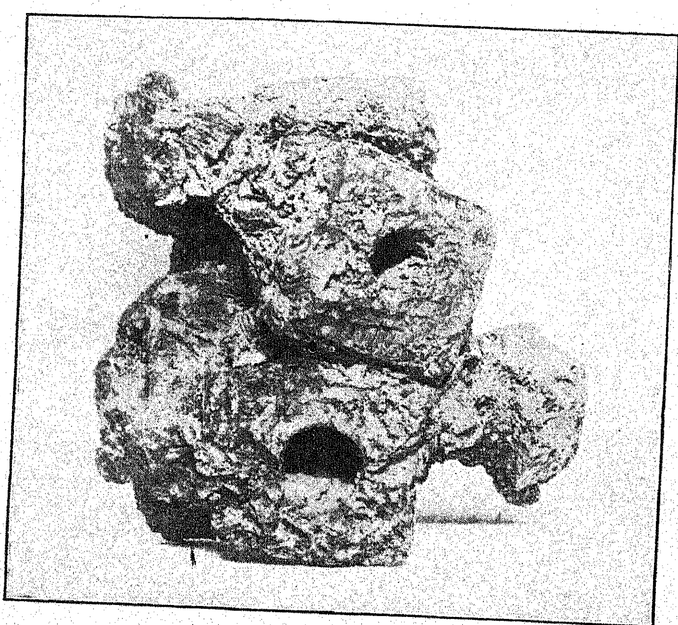

Fig. 12.
To illustrate process of solidification at present. A group of railway spikes cemented by a deposit of iron, after a burial of a few years in a railway embankment.

The same is true of lava. There is every gradation between the liquid lava and the cold, solid rock; and it would be difficult indeed to say just when a lava ceased to be a liquid and became a rock.

The rocks of the earth's crust are formed in one of five ways: (1) by the solidification of molten rock, as the lavas; (2) by chemical precipitation from water, as illustrated by the beds of salt; (3) by the action of animals or plants, as in the case of coral and coal strata; (4) by the mechanical destruction of other rocks, as in the sand and clay beds; and (5) by the alteration, or metamorphism, of one of these classes of rock, as in the case of marble. The first are called *igneous* rocks, the second, third, and fourth are grouped as *sedimentary*, and the fifth as *metamorphic*. It is only the first of these that are considered in this chapter.

FIG. 13.
Consolidated gravel layer in a pit, from which loose gravel is being taken.

Origin of Igneous Rocks. — As is stated in Chapter XVIII., there are places in the earth from which molten rock rises to the surface, from some point within the crust. Usually the lava rises through a tubular vent and builds a volcanic cone, though sometimes it wells up through fissures and flows away as great floods. Deep down in the earth these lavas are rising, but, failing to reach the surface, are spreading out between

the rocks and cooling there. These are *intruded* or *plutonic* rocks.

In all cases, in the course of time, these must become

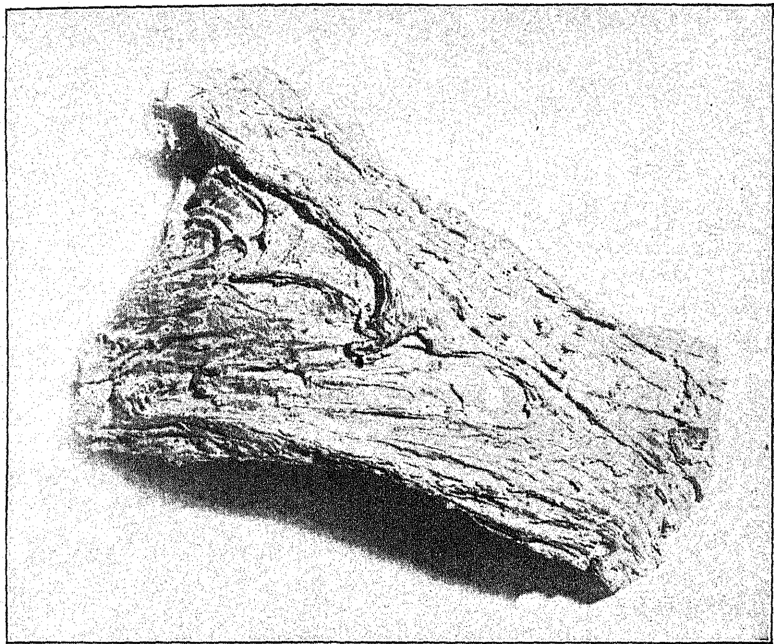

Fig. 14.

A piece of lava from surface of a flow, showing ropy surface, caused by flowing just before cooling.

cold and hard. If they are buried deep within the crust, they may lie for ages hidden from view; but, as the surface of the land is destroyed and melts down, they may in time be reached, and we then have re-

vealed, the kind of rocks that are formed under these conditions. Our granite quarries furnish illustrations of such intrusions.

A molten rock that reaches the surface is said to be erupted or extruded; and the rock that is formed is

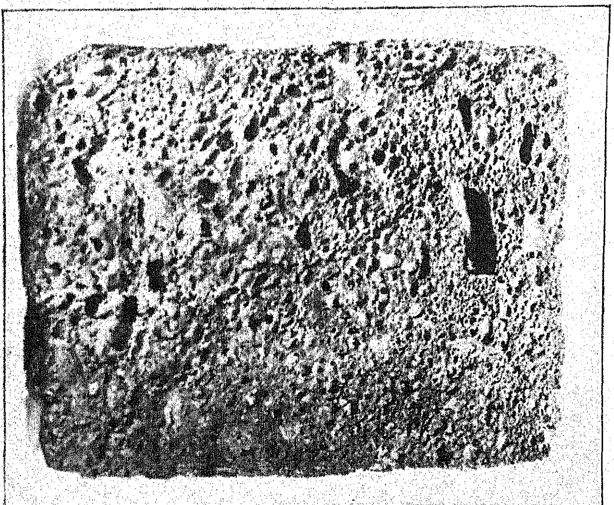

FIG. 15.

A lava rock with many gas-made cavities caused by expansion of steam.

called a *volcanic*, an *eruptive*, or an *extrusive* igneous rock (sometimes effusive). If it flows away, somewhat like water, as in the Hawaiian Islands, it is a *lava flow*, and the eruptive is a *lava* (Figs. 14, 201, and 202).

In volcanoes one of the important elements is steam; for, as with a bursting boiler, the sudden eruption of

a volcano is a steam explosion (Figs. 15 and 203). Sometimes the explosion is very violent and the molten lava is blown into shreds and cast high in the air, forming an ash-like product which is called *volcanic ash* or *pumice* (Fig. 16). So in an eruptive rock we may have two extremes, either a solid lava or a porous pumice, blown full of holes by the expansion of steam; and between these extremes there is every gradation. Sometimes the lava is blown into shreds, and even into hair-like threads of natural glass. The cavities caused by the expansion of the steam usually have smooth rounded walls (Fig. 16).

FIG. 16.
Photograph of a piece of pumice.

Texture of Igneous Rocks.—In the molten lava there are many elements, perhaps a score or two, which because of the heat, are prevented from combin-

them, cool much more slowly. These intrusive or plutonic rocks can cool only as fast as their heat can be carried away through the crust which surrounds them. Rocks conduct heat slowly,[1] and so we may say that these intruded masses are surrounded by a blanket, which prevents their rapid cooling. It may take thousands of years for a deeply buried lava intrusion

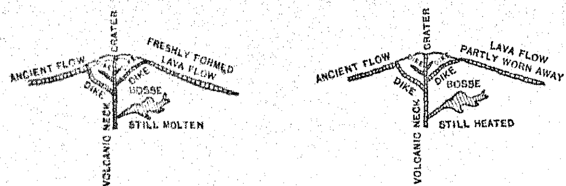

Fig. 21.

To illustrate intrusion of rocks and rate of cooling. Left-hand figure, a volcano recently in eruption. Right-hand figure, the same several centuries later.

to solidify; and this allows the minerals to grow to a good size. So as a general rule (though there are some exceptions) the surface flows are fine grained or glassy, and the intruded rocks of coarser texture.

Let us suppose that Vesuvius is in eruption for the last time (Fig. 21). From the tube of the volcano a lava flow is running down the mountain side and cooling rapidly. In the tube, down to the reservoir which is furnishing the lava, is molten rock; and perhaps from this

[1] To illustrate the slow conduction of heat by rocks, it may be pointed out that the heat of the summer sun does not produce any effect on the temperature of the earth at a depth of fifty to sixty feet, and its effect is almost limited to the upper ten feet.

there are streams of lava extending into fissures in the earth, but not reaching the surface. These deeply buried

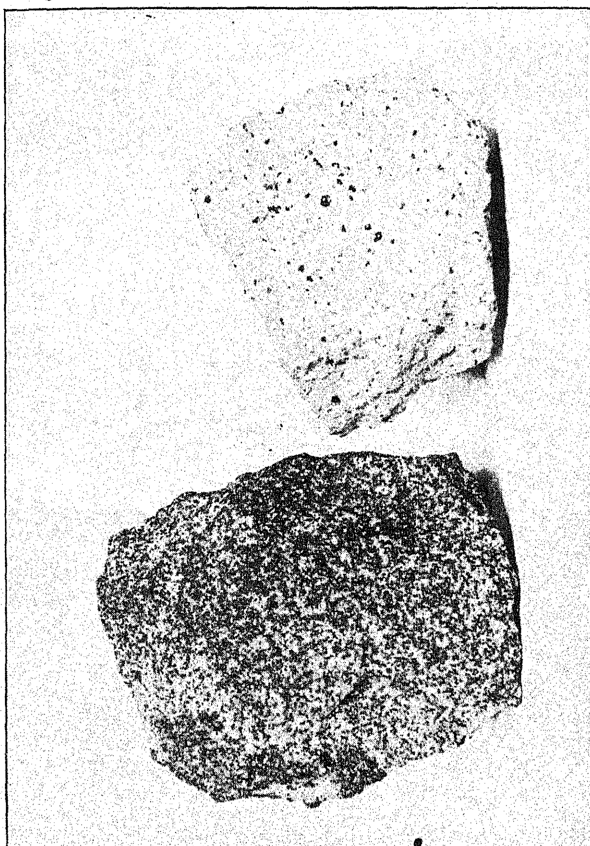

PLATE 2.

Two fine-grained or cryptocrystalline rocks. Diabase, a black rock, on the left; rhyolite, a light-colored rock, on the right.

intrusions will be molten for many centuries after the surface lava has cooled; and slowly they will become

solidified and crystalline. From top to bottom the material is the same; but the rocks which result will differ greatly in appearance. At the surface may be glass and a fine-grained lava (Fig. 19 and Plate 2); but deep down in the earth a granite rock is formed (Fig. 20). Geologists classify igneous rocks, and give them names, according to the variations in texture, as is illustrated in the table on p. 66.

Variation in Composition. — But volcanoes in different parts of the earth, reach down to reservoirs which furnish entirely different kinds of lava. That from the Mexican volcanoes, for instance, is light in color, while the lava of the Hawaiian Islands is dense black. When subjected to a chemical analysis, these are found to differ in the kind and proportion of elements. The lighter lavas have more of the acid-forming elements (of which silicon is an example), and these are said to be *acid* rocks; the darker, or *basic* lavas contain a smaller percentage of acid-forming elements, and more of the basic (potassium, magnesium, iron, etc.). With this difference there is a variation in the minerals; for with much silicon, for instance, quartz can be formed in abundance, while it must be nearly if not quite absent from the basic lavas, which contain a small percentage of silicon.

Classification. — So igneous rocks are classified and given names (1) according to their texture, which

depends upon their mode of cooling, and hence their *position* in the earth; (2) according to the minerals of which they are composed, these being determined in great part by the *chemical composition* of the lava. In the table[1] which follows (p. 66), the difference in texture is represented by vertical position, the lower being coarse grained; and the chemical or mineralogical difference is indicated by the horizontal divisions, those on the left being most acid, those on the right, basic. Names of the minerals contained are given at the top of the columns.

Igneous Rock Structure. — All the igneous rocks, excepting volcanic ash and glass, are characterized by a crystalline structure, though in some of the fine-grained varieties, the crystals cannot be seen without a microscope. Frequently in the *groundmass* of glass, or almost indistinguishable mineral particles, there are larger and quite perfect crystals; such lavas are called *porphyritic* (Fig. 22). These porphyritic crystals often have the perfect outline, with the natural crystal angles

[1] This table includes only a few of the most common igneous rocks. To be understood they must be handled and studied. Introduction of the less common rocks into the table would lead to confusion; for the distinction of the various species by the eye is not easy, though with the aid of the microscope, geologists can detect differences undiscoverable by the natural sight. I would suggest a set of rocks to illustrate ash, natural glass, light-colored lava (rhyolite or trachyte), dark-colored lava (basalt and diabase), light-colored, coarse-grained rock (granite and syenite), dark-colored, coarse-grained or plutonic rocks (gabbro and diorite), and porphyritic rock.

A CLASSIFICATION OF THE COMMON IGNEOUS ROCKS[1]

		ACID ROCKS. (Generally light colored.)		INTERMEDIATE.	BASIC ROCKS. (Generally dark colored and often black.)	
		Feldspar, chiefly Orthoclase. Also with either Mica, or Hornblende, or more rarely Augite.			Feldspar, chiefly Plagioclase.	Feldspar-Free Rocks.
		With Quartz.	Without Quartz.	With Hornblende or Mica.	With Augite or other Pyroxenes.	
Eruptive, Volcanic, or Effusive Rocks.	All either glassy or fine grained; usually porphyritic; have either reached the surface or been intruded nearly to the surface. Any of these may occur as volcanic ash.	RHYOLITE.	TRACHYTE.	HORNBLENDE and MICA ANDESITE.	AUGITE ANDESITE, and BASALT. DIABASE (or trap).	Rare.
Abyssal, Plutonic, or Intrusive Rocks.	Mostly coarse grained; rarely porphyritic; have been intruded into the crust often at great depths.	GRANITE.	SYENITE.	DIORITE.	GABBRO and NORITE.	PERIDOTITE, etc. Mostly uncommon.

[1] There are many other kinds of igneous rocks recognized by geologists; but those in the table are the most commonly known and most easily distinguished. For a study of these in greater detail, the use of the microscope must be introduced.

and planes; but at times the boundaries are rounded and eaten by the hot lava in which they grew. They were developed while the rock was cooling from the fluid state.

More rarely some of the minerals form balls, known as *spherulites* (Fig. 23), in which the minerals radiate

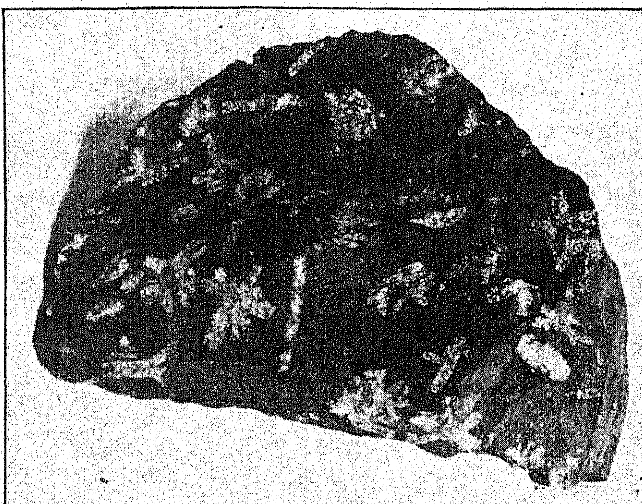

FIG. 22.

Photograph of a porphyritic rock with crystals of feldspar in a black, crypto-crystalline groundmass.

from a centre like the spokes of a wheel. Many lavas have numerous cavities where steam has expanded while the rock was cooling (Fig. 15); and if, later, these are filled with minerals, the filled cavities are called *amyg-*

dules, and the rock an *amygdaloid* (Fig. 24). Calcite is one of the most common minerals in these cavities, but there are many others which are sometimes present.

The rough surface of a lava flow or of a lava rock, caused by the expansion of steam, is sometimes so full

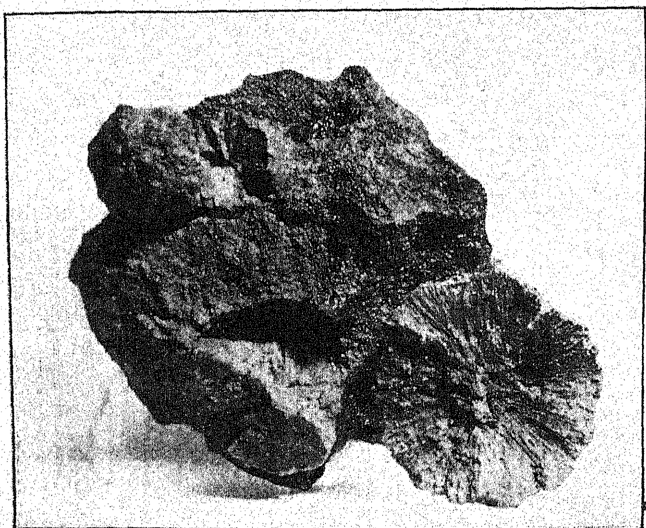

FIG. 23.

Spherulites in an obsidian rock from Yellowstone Park.

of gas cavities that it is, in this respect, almost like a volcanic ash. It is then called a *pumiceous* or *scoriaceous* lava. A *slaggy* lava is one which resembles common furnace slag; and some of this is so like lava that it might be confused with it unless carefully examined.

One of the ways in which the igneous rocks differ from the other two classes, is in the general absence of a banding, though to this there are exceptions. Lavas that are nearly solidified flow like molasses, and just

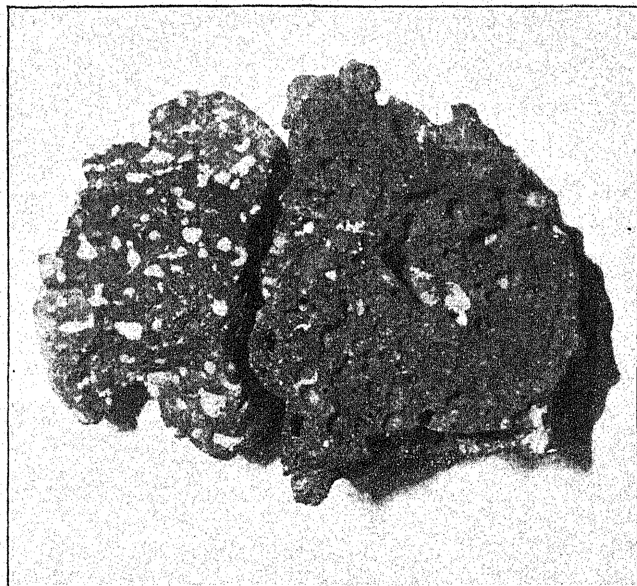

FIG. 24.

Porous lava, on right, and amygdaloidal rock, on left.

before they cease moving, there may be some minerals already formed, especially the porphyritic minerals. If so, these may be arranged in bands or layers, giving a kind of imitation stratification which is known as

the *flow structure* (Fig. 25). This rather indistinct banding is relatively rare and quite different from that of other rocks. As a general statement, it may be said, that excepting for this, igneous rocks are massive. Not only do they differ from the sedimentary and metamorphic strata in this respect, but they also differ from the former in the fact that they are usually glassy, or else show signs of crystalline structure.

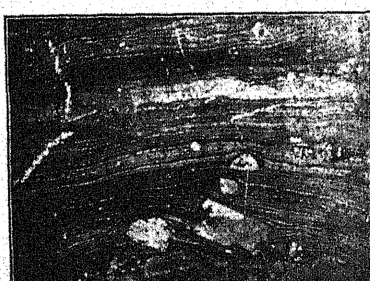

FIG. 25.

Flow structure in lava, enlarged by microscope. Bands bent around the porphyritic crystals.

Distribution of Igneous Rocks. — The eruptive rocks are found most abundantly in the neighborhood of volcanic cones, which are either erupting lava or ash at present, or have recently done so; but they occur in other places as well. In New Jersey, Connecticut, and the Palisades of the Hudson, for instance, although there has been no eruptive action there for many geological ages, lavas are found, testifying to former volcanic energy in volcanoes long since extinct. In New England, too, there are great areas of granite, and other igneous rocks, which were once intruded deep in the earth, and are now revealed by the wasting away of the solid blanket of overlying strata.

CHAPTER V

SEDIMENTARY AND METAMORPHIC ROCKS

Stratified or Sedimentary Rocks

Terms used. — The term *sedimentary* is not satisfactory, for it assumes that the rock is actually a sediment; and in this group we must include some kinds which are not really sedimentary in origin. Sometimes the members of this group are called *stratified*, because they occur in layers or strata, but there are certain members of which this is not true. Many of the so-called sedimentary beds are composed of fragments of other rocks, and these are often called *fragmental* or *clastic*. Most of them are formed in water, and these might be called *aqueous*. Rather than invent terms, we will use the names *sedimentary* and *stratified*, with the understanding that some of the members included are neither true sediments nor stratified.

Origin of the Rocks. — As is stated elsewhere (see Chapter VI.), when exposed at the surface, minerals are subjected to destruction. The beating of waves on the seashore, the grinding of pebbles in the bottom

of streams, and other causes, wear the minerals into fragments by mechanical action. The fragments thus obtained may be gathered into beds or layers, forming new kinds of rocks in the sea.

Again, the action of the water and air causes some of the minerals to decay, and the rocks to crumble. These soil fragments may be washed away by rivers or waves, and gathered into beds of rock fragments. At the same time, from the decay of minerals, soluble salts are formed, and under favorable conditions these may be borne away by the water and deposited in layers. Plants or animals may take mineral substances from the earth or water, which upon their death are accumulated into beds, and thus made to again enter into the construction of rocks.

Any rock may disintegrate either by mechanical or chemical means, though some do so more readily than others. Let us take granite as an instance of a rock exposed to the disintegrating action of the air. When it first became a solid, as a result of the cooling of melted lava, it had a temperature certainly many hundred degrees above the boiling-point of water. So when finally exposed to the air and to percolating water, the minerals of the granite find themselves existing under conditions of temperature different from those that were present when they developed. Some of them are ready for change.

The quartz will waste very slowly, and then only as it is dissolved, for it will not be altered chemically. The feldspar and the hornblende, being more complex, are less durable, and they soon commence to change, and finally become a clay from which some of the elements go off in solution. Left without support, as a result of the decay of these minerals, the quartz grains fall out and the granite crumbles (Fig. 47). From the original minerals of the rock, three quite different products result: (1) soluble salts, (2) fine clayey fragments, and (3) larger grains of pure quartz. What is true of granite is true in greater or less degree of all rocks; and everywhere in Nature's great laboratory such changes as these are in progress at the surface.

According to the way in which these mineral products are gathered into layers or *strata*, we have three different groups of sedimentary rocks: (1) fragmental or clastic, (2) chemical precipitates, (3) organic. The second, and some members of the first and third, are aqueous; nearly all are stratified; and some of each group are truly sedimentary.

Fragmental or Clastic Rocks. — *Origin.* These are composed of distinct fragments of other rocks, and these particles may be gathered into layers by one of four means: (1) the wind, (2) ice, (3) water, (4) volcanic eruption.

The wind can carry only fine grains of clay or sand;

and so the texture of all strata that are derived by this means is that of fine grains. Ice can carry fragments of any size, as can the other two agents. Hence rocks derived by means of these, can be of any texture from finest to coarsest.

The size of the fragments transported by the wind or water will depend upon the velocity with which these are moving. Therefore by the action of these agents the fragments are assorted into layers, according to their texture, the coarsest being moved only by the strong currents, while the finer may settle in quiet water or air. This gives rise to banding or *stratification* (Figs. 26, 82, 85, Plates 4, 6, 7, etc.). In a measure this is true also of the fragments from volcanic eruptions, for the larger pieces fall first, and usually near the cone, while the finer ash may drift for days, and even months, falling scores or hundreds of miles away. Ice, on the other hand, carries a bowlder as easily as it does a particle of sand; and so ice-formed beds are mixed in texture, and not assorted into layers.

The wind, volcanoes, and ice (glaciers), may build beds of rock fragments *on* the land, or they may sweep them into the river, the lake, or the sea. Those beds formed by water are deposited under its surface, and in most cases are permanently covered by it, although on the beach, and on the river floodplains, they may be above the water during the greater part of the year.

The majority of the sedimentary rocks, however, have been formed in the ocean, and it is these which are of chief importance in geology.

Soil Rock. The fragmental rocks are named according to their texture. The soil, which is usually the

FIG. 26.

A pebble made of two layers, pebbles above and sand below.

result of the disintegration of the rocks, is one of the most common. It varies in texture from clay to gravel, and is really a gradation between the solid rock and the fragmental deposits which are made by its removal (see p. 120).

Pebbly Rocks. At the base of a cliff there is an

accumulation of *talus* material (Fig. 58) formed of angular pieces produced by the disintegration of the cliff. This coarse mass of angular fragments is *breccia* (Fig. 27), and it may be formed at the base of a cliff either on the land, or in the sea or lake. The deposits formed by a glacier are also of this nature,

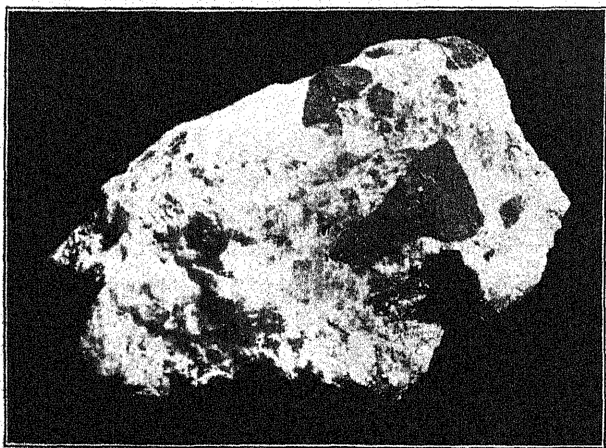

FIG. 27.
A breccia.

being composed of large, angular fragments, enclosed in a matrix of finer particles. These are well illustrated in the soils of the northeastern states and Canada (p. 121).

In the beds of many rivers, and on the pebbly beach (Fig. 28), the rock fragments are rounded, forming

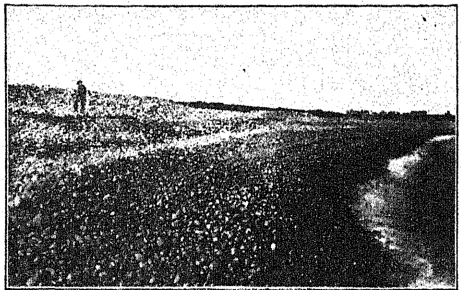

Fig. 28.

A pebble beach, Cape Ann, Mass.

pebble or gravel beds; and when these are consolidated into a hard rock, they become what is known as a *conglomerate* (Figs. 26 and 29). Between the rounded pebbles there is usually a matrix of sand, and the large and small fragments are bound together by some kind of cement which consolidates the rock. There may be a very decided difference in the *size* and *kinds* of the pebbles, and there are limestone conglomerates, shell conglomerates (*coquina*) (Fig. 30), quartz-pebble conglomerates, granite-pebble conglomer-

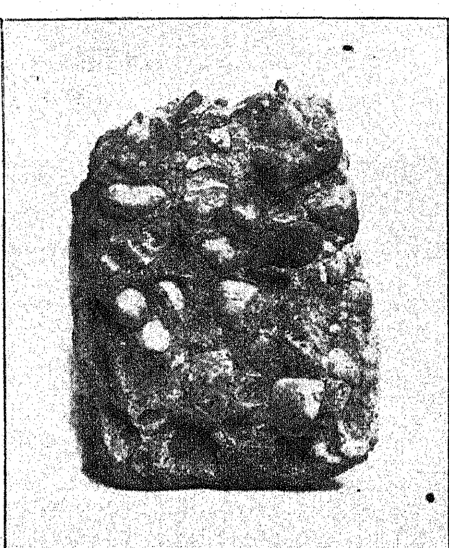

Fig. 29.

A conglomerate rock.

ates, etc. There may also be volcanic conglomerates, composed of the larger fragments of volcanic pumice and ash.

Sandy Rocks. As the wind blows over a desert country (Fig. 59), or across a beach, it may pick up particles of sand and pile them into hills (Fig. 62), or

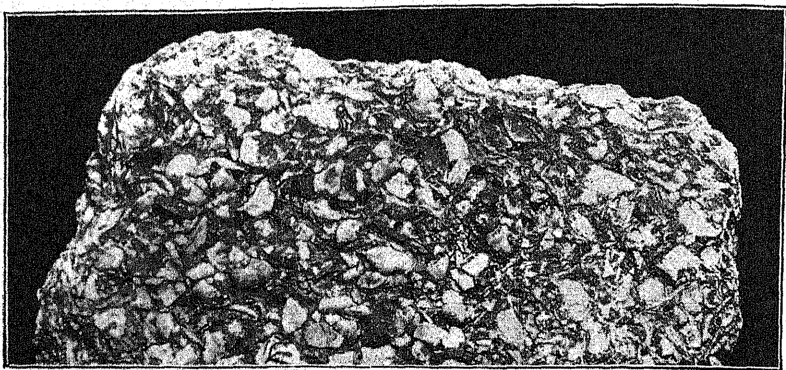

Fig. 30.
A coquina rock.

spread them over the land in layers. The current of a river, or the waves of lake or sea may gather sand into beds (Fig. 31). When consolidated, these sand beds form *sandstones* (Fig. 32).

In texture these may be coarse, grading into a conglomerate (Fig. 26), or very fine in grain, almost like a clay (as in the bluestone which is used for flagging). They are usually composed of grains of quartz, the

most common mineral that resists disintegration, and therefore does not crumble to form clay; but there

FIG. 31.
A sand beach, Cape Ann, Mass.

are also shell sands, magnetite sands, garnetiferous sands, etc.

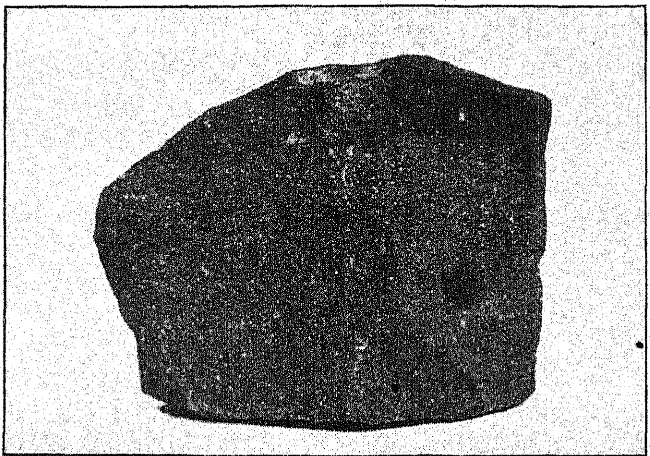

FIG. 32.
A sandstone rock.

According to the cement which consolidates the sand grains, sandstones have been given different names: if the rock is clayey, it is called an *argillaceous sandstone*, or if the grain is very fine, it may be called an *arenaceous clay*. If the cement is lime, as in some of the light-colored beds, the product is called *calcareous* sandstone; if the cement is of iron, the rock is *ferruginous*, as in the brown and red sandstones; or the rock may have a cement of silica, when it is said to be *silicious*.

In some sandstones there are many angular fragments, often giving the rock the character of a *grit*, which adapts it for use in grindstones; in other cases the rock splits easily in every direction, and it is then called a *freestone;* and yet again, owing to the presence of many mica flakes, it cleaves readily in only one direction and is said to be *shaly* or *micaceous sandstone.* But while there are many different kinds, they are all alike in the fact that they are composed of small, visible grains of sand, usually quartz.

Clayey Rocks. The fine clayey soil is an illustration of a third group of the fragmental class, which may be called the clay rocks. The clayey fragments may be moved by the wind and gathered into beds on the land, as in northern China, where thousands of square miles are covered by a wind-blown clay, called *loess* (Fig. 60). They may also be accumulated in any body of water where the currents are quiet, — on the

river floodplain, in the lake bottom, on the ocean floor, or in quiet bays along the shores of the ocean. These clay rocks are frequently so constructed that they readily split into layers. Such a rock is called a *shale.* Its habit of splitting depends upon the presence of many minute particles of flattish minerals, often mica.

Near coral islands, the grinding action of the waves on the beaches wears the coral fragments into a fine clay. This settles on the bottom, forming a limy mud, which may afterwards become transformed to a *limestone.*[1] There are many other kinds of clay rocks, such as the *kaolin clay*, formed by the decay of feldspar; or *fire clay*, which has lost its alkalies by the action of plants which grew upon it, and extracted these substances for their own needs, leaving the clay so free of alkali that it resists the action of fire. Besides these, there are sandy, or *arenaceous clays* which contain considerable fine sand, *carbonaceous clays*, which contain abundant fragments of plants, etc.

Among either of these three groups of fragmental rocks, there may be beds of volcanic origin; and as much of the volcanic ash and pumice floats into the sea, it may be gathered into layers, mixed with fragments from other sources. When a layer of rock is composed mainly of volcanic materials, it is called a *tuff.*

[1] This is but one of several ways in which limestone beds may be accumulated (see pp. 84 and 89).

Chemically precipitated Rocks. — *Solvent Power of Water.* As water flows or seeps through the ground, and even as it runs over the surface, it finds materials that it can carry away in solution. Even minerals (such as quartz) which do not appear to be soluble, may be taken up in minute quantities; but it is not to be understood that this power of solution is usually due to the water itself. Pure rain water has little power of dissolving most minerals.

From the decaying leaves, and indeed from the air, the rain absorbs impurities, such as carbonic acid gas. In passing through the decaying leaves, water may unite with the humic acids, or it may encounter alkaline substances which are easily dissolved; and in going through the soil, it may find readily soluble substances which have been introduced by the decay of the rock-forming minerals. These impurities transform water in some cases into a weak acid, in others a weak alkali; and in this condition it can do work of solution, for it may either be able to attack the minerals directly, or substances may have been prepared for it by the previous decay of the minerals.

If water is warmed, it will dissolve more salt or sugar than it could if cold; and so, also, as the temperature of water increases in the earth, its power of solution is correspondingly increased. Therefore, in some places, as at the outlet of a hot spring, the water

is bringing from within the earth much more material than it could if its temperature were lower; but all water in the earth acts as a solvent, although under different conditions there is a variation in the amount and kind of material dissolved.

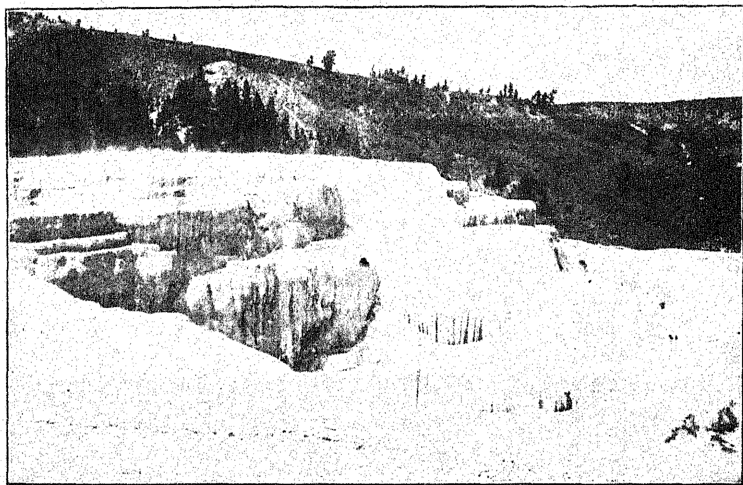

FIG. 33.

Calcareous rock deposited by hot springs in Yellowstone Park.

Deposit from Warm Water. Under favorable circumstances, some or all of this load of dissolved material may be deposited. For instance, when water reaches the surface in the form of a hot spring, as it does so commonly in the Yellowstone Park, and in many other parts of the earth, it bears with it some minerals in

solution. As the temperature decreases in contact with the cold air, some of this material must be precipitated. So in the Yellowstone region, there are extensive beds of carbonate of lime formed near the hot springs (Fig. 33). When porous and spongy in texture, this is called *calcareous tufa* or *travertine.*

In the neighboring geysers (Figs. 220 and 221), silica is being brought up by the hot water; and as it is spread out in layers, it builds a rock which is called *silicious sinter* (Fig. 34). Around hot springs other deposits are being made, and there is every reason to believe that at a depth of hundreds or thousands of feet in the earth, these hot spring waters are forming mineral veins (p. 380), perhaps of silver, gold, copper, or other metal.

FIG. 34.
Silicious deposit, Sapphire Pool, Yellowstone Park.

Deposit in Caves. A second important way in which rocks are chemically precipitated, is illustrated in caverns (p. 140), where pendent *stalactites* of carbonate of lime grow from the limestone roof at those places where water is slowly entering along some crevice

(Fig. 35). This water carries carbonic acid gas; and, so charged, is able to dissolve some of the carbonate of lime of the rock through which it passes. When the water enters the cave, a portion of the carbonic acid gas escapes. The solvent power of the water is

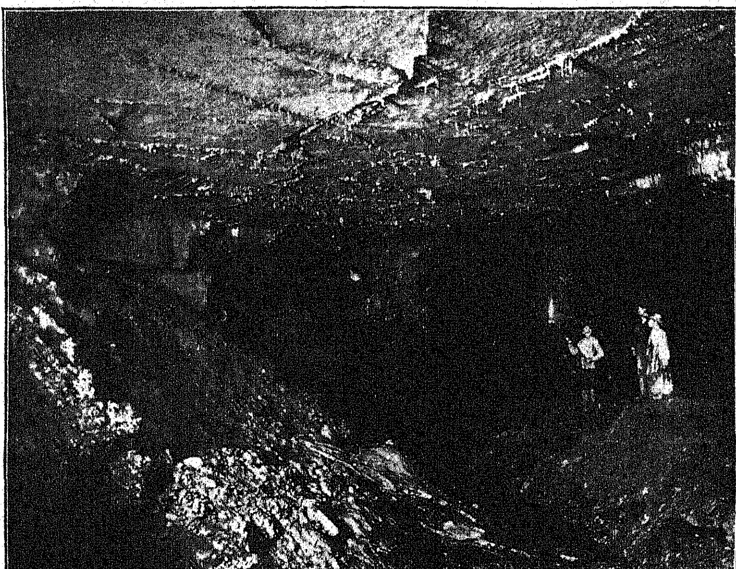

Fig. 35.
Stalactites in a cave. (Copyright, 1889, by S. R. Stoddard, Glens Falls, N. Y.)

then decreased, so that, of necessity, some of the lime is deposited in the form of a stalactite. In somewhat the same way, deposits of *bog iron ore* are formed at the outlet of iron-bearing springs, where the ferruginous waters come in contact with the air.

Deposit in the Rocks. While chemically precipitated rocks are interesting, they are not very important; but chemical precipitation is of great consequence *in* the rocks. As it passes through them, water often takes a mineral in solution at one place, and deposits it in another, and this is one of the ways in which rocks are cemented (see pp. 52 and 273). In its passage through the earth, too, water is often producing change by a series of chemical reactions, the nature of which cannot be considered here. In some places entire beds of rock are completely changed in kind by this chemical action of water. For instance, certain limestones have been altered to magnesium limestone, or dolomite, while others have been changed to iron beds by the precipitation of siderite, or other salt of iron, from some solution of iron in water. Some valuable iron-ore deposits (such as those of the Lake Superior district) are of this origin. In a similar manner limestone beds have been changed to gypsum.

Deposit by Evaporation. The last important way in which the chemical action of water is at work in making beds of rock, is by evaporation. In almost any region, but particularly in an arid country like that of the Far West, springs, or even streams, evaporate and leave behind the load of chemically deposited material which they carried. Thus *calcareous tufa* is deposited (Fig. 36).

Every stream carries some mineral matter in solution. The hardness of water is a proof of this, for it is the dissolved mineral which makes the water hard. In some places, as for instance in the Dead Sea and the Great Salt Lake, streams enter basins from which there is no outlet. The pure water evaporates, leaving the chemical impurities behind; and, in course of

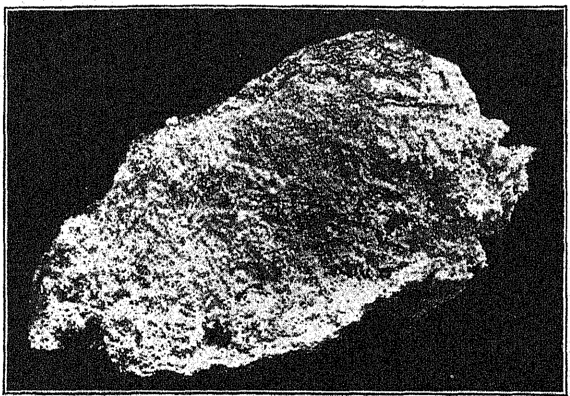

FIG. 36.

Calcareous tufa.

time, the small contributions of the streams, render these waters more impure than the ocean. Since salt is one of the most common of the substances carried in solution, it is the most prominent impurity in these interior seas. In course of time, the water may become so salt that some must be deposited as rock salt. Beds of this precipitated mineral are sometimes several

hundred feet thick. Certain limestones, gypsum beds, etc.,[1] are also formed as precipitates from water which is thus subjected to evaporation.

Not only is this now happening in these places, but in past times it has occurred in many other regions (such as central Texas, Kansas, Michigan, west central New York, and elsewhere), where now the conditions of climate forbid. In these places layers of salt and gypsum are found deeply buried in the earth, bedded with other strata.

Resemblance to the other Rocks. Since these rocks are deposited in water, they are often crystalline, though this is by no means a necessary condition. These differ from most of the other crystalline rocks in the fact that they are made, not of several minerals combined, but of a single mineral, though this is often mixed with minor quantities of impurities. Moreover, they are deposited in layers and therefore are stratified, though in a single small specimen the distinct bands may not be visible.

There is no certain test by which the small specimen of limestone, which is precipitated by one of these agencies, can invariably be told from another that has been derived either by mechanical or organic action; and

[1] Some of these rocks are described under other headings; but no description of their characteristics is attempted, for it is believed that the only way of learning these is for each student to examine and observe from actual specimens.

so the student can hardly be expected to decide which are chemical, which organic, and which mechanical. There are, however, no chemical forms of conglomerates, sandstones, or clays, but only rocks like those described in this section. Moreover, since they are accumulated under conditions of a peculiar nature, there is a general absence of fossil remains. In a dead sea, for instance, animal and plant life are nearly absent.

Organic Rocks. — *Calcareous Rocks.* Both animals and plants are engaged in making strata. Animals on the land do not usually have an opportunity, because they do not live in great colonies, and when they die their bodies soon decay. In the ocean, on the other hand, there are reefs built of coral fragments, which themselves are made of carbonate of lime that the coral animals have extracted from the ocean water. This in turn is dependent on the land for its supply of lime, which is obtained by the action of water in the rocks.

Of this origin are the majority of the limestone beds of the world; and even now great strata of these rocks are being thus formed in the sea. We may have a limestone composed of fragments of shells, such as the coquina (Fig. 30) of the Florida coast; or it may be a coral rock fashioned almost entirely of pieces of coral; or it may be made of microscopic calcareous sea-shells, floating for a time at the ocean surface, and

finally dropping to the bottom. On a great part of the ocean floor there is an ooze or limestone mud (p. 257), which is now forming deposits like the chalk, whose origin is similar to this. This deposit on the ocean bed is called Globigerina ooze.

In the past geological ages, a species of animal, now very rare in the ocean (the crinoid), built limestone beds which are known as *crinoidal limestones*. Accumulations of shells sometimes gather on the bottom of lakes, forming *marl*, a whitish clay containing many shells.

These limestones, whatever their origin, are all made of carbonate of lime; and when a drop of hydrochloric acid is placed upon them, they effervesce like calcite. They are soft rocks, easily dissolved, varying in color from pure white to black. There are numerous impurities, and the color is often due to these. One of the most common adulterations is clay, and when this is present in high percentage, the rock is called an *argillaceous limestone*, which grades into calcareous clay rock. In them are usually found many fossil fragments of shells or corals (Fig. 37); and some of the so-called marble, which is used for mantles, etc., owes its beauty to these fossils, which are brought out distinctly on the polished surface (Fig. 38).

Silicious Rocks. Other rocks of animal origin are less common. In the shallow lakes, and beneath some

of the swamps, which are really destroyed lakes, there is often found a layer of powdery silica, so gritty that it is used for purposes of polishing. This is *infusorial earth*, being composed of the silicious skeletons of microscopic animals belonging to the group of Infu-

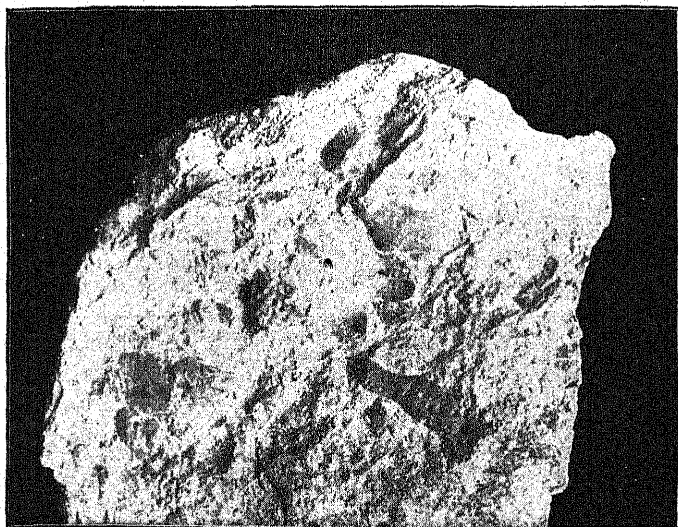

FIG. 37.

Limestone rock with fragments of coral, crinoids, and other fossils.

soria. Sometimes this deposit is *diatomaceous earth*, so named because it contains large numbers of silicious shells of a plant belonging to the group of diatoms.

Phosphate Rocks. In some places, as for instance near Charleston, S. C., and in Florida, the bones of

large marine and land animals have been accumulated into bone beds. These form *phosphate rocks* which are used as fertilizers. *Guano*, which is found on islands off the coast of Chile, is made of the excrement of birds that lived in great numbers on these islands.

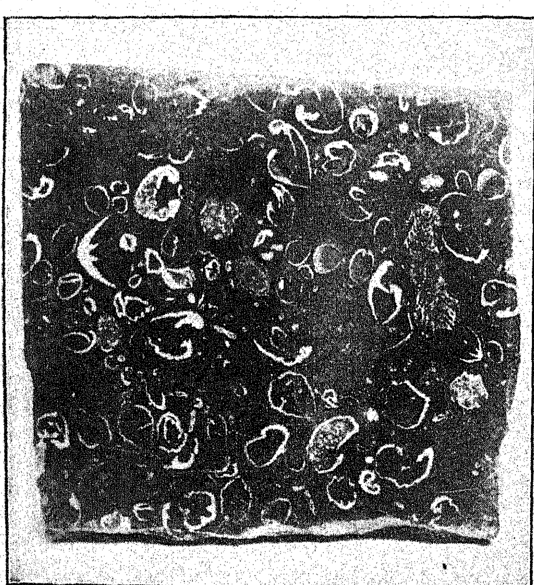

FIG. 38.

A limestone rock polished as a marble, so that sections of shells (Brachiopoda) show with distinctness.

Plant Deposits. In the sea, plants do not exist in sufficient abundance to make beds of rock, although they are of aid in the formation of some strata. On the land, plants take carbon from the air and mineral

substances from the waters which they draw out of the soil through their roots. These substances they build into their structure; but when the plants die, they are in large part returned to the air or earth. In favorable places, particularly in swamps, where decay is retarded, the plant remains may accumulate in beds

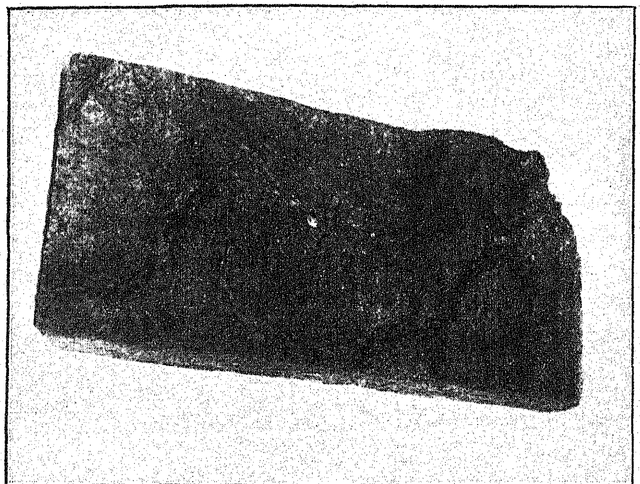

FIG. 39.

Piece of dried peat, showing cast of roots. Made entirely of plant fragments.

of *peat* (Fig. 39), and these may later become transformed to *coal* or mineral fuel, which is mainly made of carbon.

Between the peat, which we see forming in the swamps, and the hardest anthracite coal, there is every gradation. *Lignite* or *brown coal* is a form of fuel

which so closely resembles peat, that it still shows the plant remains and is so soft as to soil the hand. *Bituminous coal* has been partially transformed, and, although it is sometimes seen to contain plant frag-

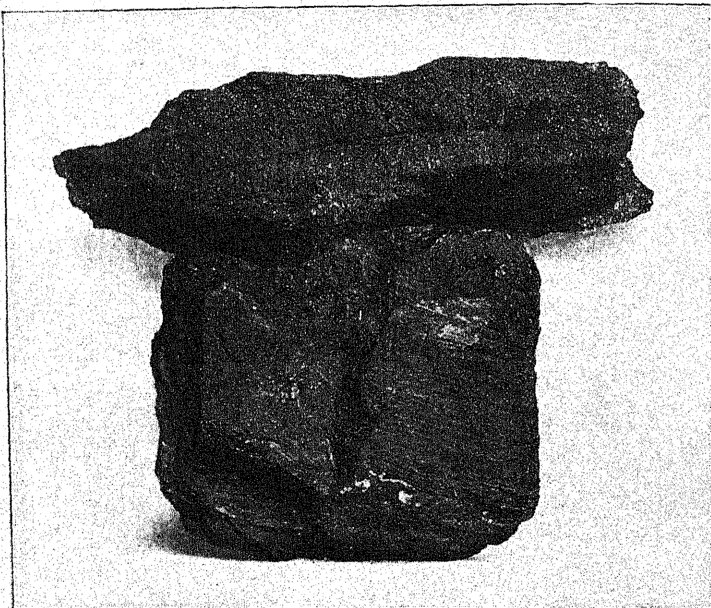

FIG. 40.
Carbonaceous shale with thin laminæ of coal and impressions of plants. Taken from mine above layer of bituminous coal.

ments (Fig. 40), it does not look like peat or lignite, and is so hard that it easily passes for a rock. The next stage in the transformation is the hard, black *anthracite*, and in some cases the change has gone so far that the coal is partly mineral carbon, or *graphite*.

Other Organic Rocks. There are other forms of rock which are directly or indirectly of organic origin, and nearly all the sedimentary strata have some animal or plant remains. Some of the iron deposits of the bogs, such as the *bog iron ore* (see also p. 85), are made possible by the presence of organic acids produced by the decay of plants. This causes a chemical change, resulting in the accumulation of iron ore. *Flint*, and the more impure *chert*, are also made by the agency of organisms. These are dense, hard layers or nodules of silica, some of which may have been formed by silicious animals, although most appear to be of later chemical origin. They vary in color through all shades, but are usually dark.

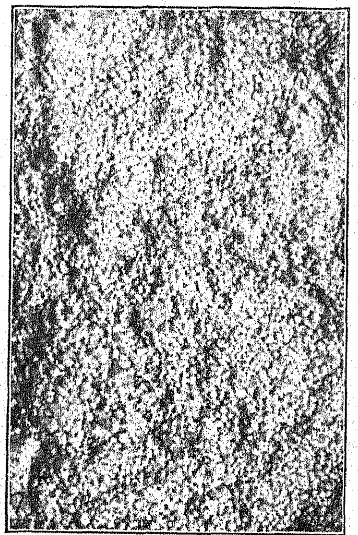

FIG. 41.
An oölite rock, showing the tiny grains resembling fish roe.

Another form of rock that is sometimes found is *oölite* (Fig. 41). This is usually a limestone, though occasionally an iron or even a silicious rock. It is made of tiny grains, like bunches of fish eggs, whence the name. Each of the rounded grains, usually minute,

is made up of concentric layers (Fig. 42) like an onion. Oölites appear to be formed in three distinct ways: (1) by the action of low forms of plants (algæ), which build up the grains; (2) by chemical deposit in water at the surface (as in the geyser region of the Yellowstone, where the balls grow to considerable size (Fig. 43)); (3) by a chemical change which causes a rock of a different origin to assume the condition of an oölite. Oölite grains are even now accumulating on many shores, as those of Florida and the Great Salt Lake.

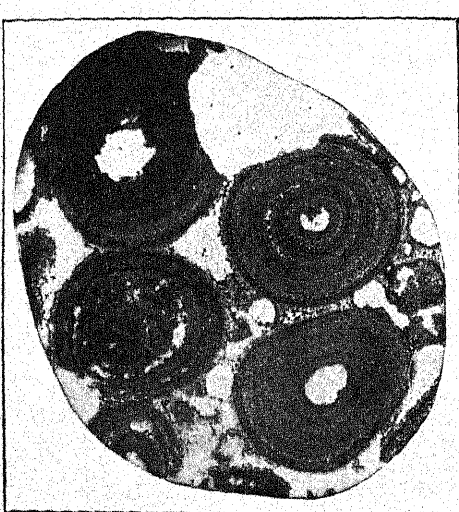

Fig. 42.
Section of oölite rock enlarged by the microscope. Several oölitic grains shown in cross-section.

Importance of Sedimentary Rocks. — The sedimentary rocks, particularly the mechanical and organic, are of the greatest importance to man, for they furnish him with most of his building-stones. At present such deposits are forming all over the globe, — on the land

CLASSIFICATION OF THE COMMON SEDIMENTARY ROCKS

		Fragmental or Clastic. Made of fragments of other rocks derived by mechanical means.	Chemically Precipitated.		Organic Rocks.
Coarse Grained.	Angular fragments.	Talus deposits; breccia; glacial bowlder clay; coarse volcanic ash; coquina.	Limestone Deposits.	Calcareous tufa; certain oölites; cave deposits (stalactites, etc.); limestones precipitated in bodies of water.	Most limestones; ocean-bottom ooze (Globigerina, etc.); some oölites.
	Rounded fragments.	Gravel beds; pebble beds; consolidated conglomerate.	Iron Deposits.	Bog iron ore; certain oölites; certain iron veins.	Not common.
Sandy or Intermediate Grain.		Sand (wind, river, lake, or ocean); fine-grained volcanic ash.	Silicious Deposits.	Silicious sinter; some oölites.	Diatomaceous earth; infusorial earth.
Clayey or Fine Grained.		Clay beds (wind, glacier, river, lake, or ocean); shale; coral clay.	Other Deposits.	Salt; gypsum.	Coal of various kinds; bone beds; guano.

and in the sea: more than one-half of the crust of the earth that is exposed to view, is made of sedimentary

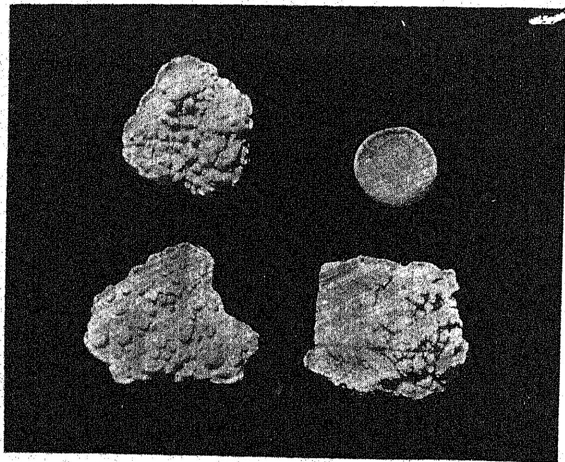

FIG. 43.
Geyserites; large oölitic balls from geyser region of Yellowstone Park. Reduced about one-half.

strata. Therefore every one should be familiar with these important rocks.[1]

METAMORPHIC ROCKS

Nature of the Process. — The nature and origin of these rocks cannot be clearly stated until some knowledge of the conditions under which they are formed is obtained: this part of the subject is taken up on

[1] No study of these or other rocks is adequate without actual examination and close study of specimens. These, like the minerals and igneous rocks, can be obtained at slight cost from the mineral dealers. (See p. 23.)

pages 322, 366. There are many changes going on in the strata of various parts of the earth's crust. The most widespread of these is that of decay, to which nearly all rocks near the surface are subjected. By this action the rocks are usually rendered weaker. This change is not the metamorphism which is meant here.

Although some rocks, such as the igneous, are solid at the beginning, many, such as the fragmental and organic, are unconsolidated. Metamorphism begins its work by solidifying these, and in some places it proceeds until they are entirely changed. If, for instance, they are subjected to heat, or to the action of heated waters, as by the intrusion of a lava mass, they may be baked or otherwise changed. This and other causes are at work producing metamorphism in the earth.

Results of Metamorphism. — Among the results of these changes is the alteration of strata, so that at a mere glance their original condition cannot be told. Sandstone becomes changed to a dense quartz rock, called *quartzite,* in which the sand grains may no longer be visible to the eye; a peat bog may be altered to *anthracite coal,* or even to the *graphite,* which we use in our pencils and which cannot be burned; a dense, apparently structureless limestone may become transformed to a beautiful white or variegated *marble,*

composed of many crystals of calcite; or a clay stratum may be metamorphosed to a *slate* (Fig. 44), in which the dense rock becomes harder, although at the same time an ability to split easily in one direction is introduced. This is called the *slaty cleavage* (Fig. 44).

The condition of the cleavage in slate, illustrates

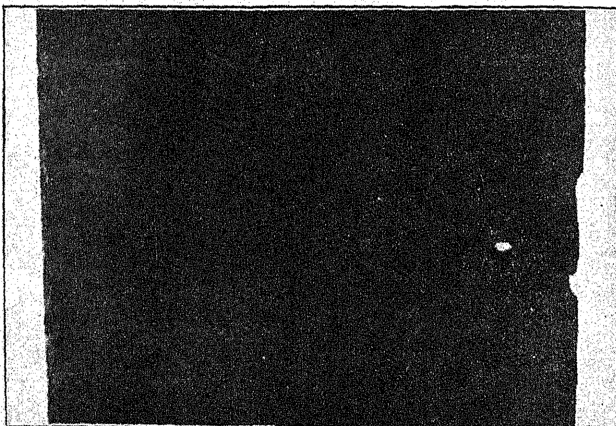

FIG. 44.

A piece of slate split along plane of slaty cleavage. The banding shows stratification planes nearly at right angles to the cleavage.

one of the features of metamorphism. It splits readily because of many plates of a micaceous mineral, developed in the rock as a result of the heat or other agent of alteration. In this change, one of the conditions is great pressure; and, as the minerals develop, they grow in a plane at right angles to the direction of the

pressure, because this is the plane of least resistance. Therefore slate splits in this direction, taking advantage of the many cleavage planes of the newly formed micaceous mineral.

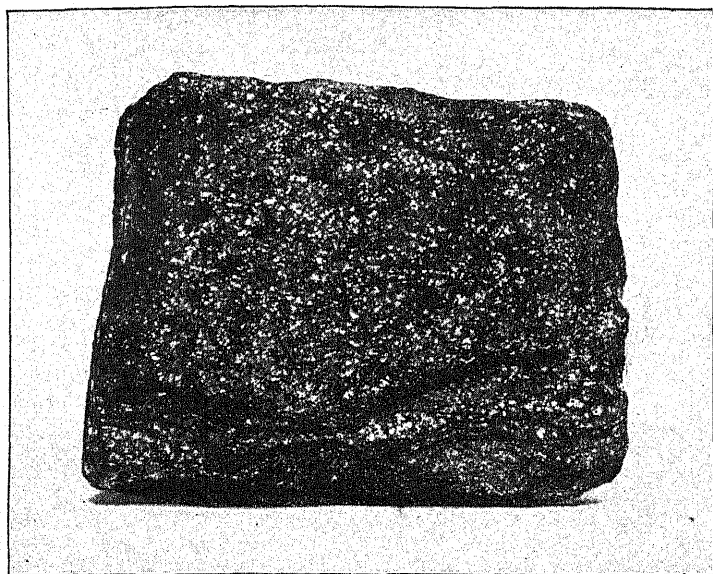

FIG. 45.

Mica schist. Schistose structure parallel to the surface. White particles are mica flakes which reflect the light from their smooth cleavage faces.

A little more metamorphism of the slate rock would develop other minerals, and soon it would become entirely different in character, a *schist* (Fig. 45), in which the various minerals are arranged in bands, and in which there is also a cleavage, though less marked

than that of slate. That is to say, the schist will split into layers much less easily and uniformly than the slate. According to the minerals present in the schist, various names are given, such as mica schist, hornblende schist, etc. All of these are characterized by

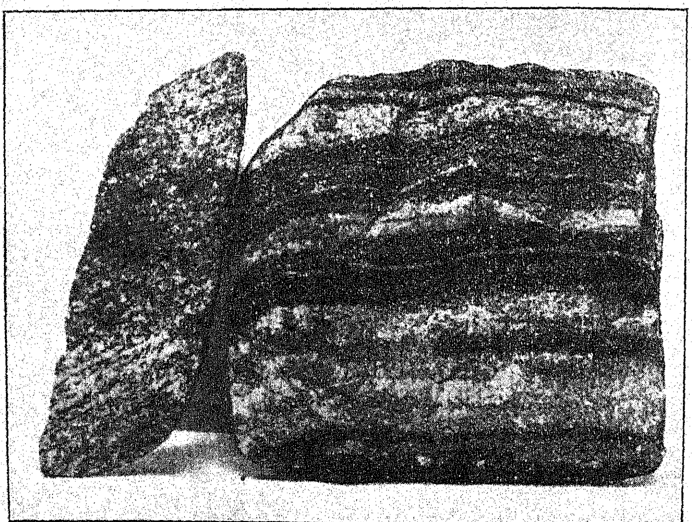

FIG. 46.
Two specimens of gneiss. Left hand specimen not so distinctly banded as right hand.

the banding and ease of splitting, which is due to the *schistose structure* arising from the banding of the minerals along planes. As in the case of slate, these planes are placed at right angles to the pressure, which was present during metamorphism.

A final change is one in which even the original condition is hidden. The last stage of metamorphism before actual melting produces gneiss (Fig. 46), which is much like a granite, excepting that it has its minerals more or less perfectly banded, while granite is massive and without layers. In the two rocks, the minerals are very often the same in kind, and in general form. There are many varieties of gneiss, whose names need not be introduced here.

Complexity of Metamorphism. — The metamorphic rocks present a large number of complex and difficult phenomena, which we are only just beginning to understand by means of careful study with the microscope. It was once thought that they represented the *original* crust of the earth, and possibly some of them do; but careful study has shown that many are merely altered conditions of other rocks.

In some places, the changes have been so well determined, that the gneiss can be shown to be an altered form of granite, or of a sedimentary or some other rock. In these cases, the changes are many and varied, including the action of heat, pressure, the presence of water, and the introduction of numerous complex chemical reactions.

Characteristics of Metamorphic Rocks. — Leaving out of consideration those rather simple forms, such as the quartzite, coal, and slate, whose origin is easily

traced to another group (the sedimentary), the metamorphic rocks are characterized by a crystalline structure. In some cases this causes them to closely resemble the igneous rocks, with which they might easily be confused, if it were not for the fact that they usually differ from these by the presence of a decided banding or foliation (Fig. 46).[1]

Since they are crystalline, there would be little danger of confusing most of them with the sedimentary rocks, notwithstanding the fact that they have a banding something like sedimentary stratification. This banding, however, is quite different from stratification, for it is an arrangement of crystalline minerals, while that of the sedimentary rocks is usually either a banding of fragments, arranged according to size, or else of differently colored layers. The metamorphic strata result from complex changes of other rocks. In these changes, the elements are often made to combine in a new manner. Given the same assemblage of elements, whether in a shale or a lava, the changes of metamorphism will produce the same results. Hence a schist may be formed either from a shale or a lava; therefore in highly altered rocks the original state can no longer be detected.

[1] Of course the rather rare flow structure (p. 70) of some of the igneous rocks may cause confusion; but when this is present distinctly enough to be seen, one can detect the evidence of liquid flow, which proves that the rock was once molten, and hence igneous.

CLASSIFICATION OF THE COMMON METAMORPHIC ROCKS

NATURE OF METAMORPHISM.	KIND OF ROCK.	SOURCE.
Less extensively metamorphosed rocks. Origin not difficult to detect.	Conglomeratic quartzite. Conglomeratic schists.	Metamorphosed from conglomerate.
	Quartzite.	From sandstone.
	Slate and certain schists.	From clay rocks.
	Marble.	From limestone.
	Certain anthracite coals and graphite.	From vegetable deposits.
	Certain schists and gneisses.	From igneous rocks.
So metamorphosed that the origin cannot be ascertained.	Most schists and gneisses. Some iron beds and marbles.	In some cases, possibly, *originally formed* this way. In others, evidently changed beyond recognition, possibly from igneous, possibly from sedimentary rocks.

Part II

DYNAMIC GEOLOGY

CHAPTER VI

WEATHERING

Denudation. — The rocks are crumbling and the earth's surface is wearing down from various causes. This process of land destruction is commonly called *denudation*. In the pages that immediately follow we will examine this subject in considerable detail.

Effect of Climate. — If a rock is exposed to the weather, it commences to crumble (Fig. 47 and Plate 3), though the rate at which this takes place, depends partly on the climate, partly on the kind of rock (Fig. 48), and partly on various other conditions described later. The obelisk of Central Park, New York City, after standing for 3400 years in the dry climate of Egypt, began immediately to decay when placed in the damp and variable air of New York. It was soon necessary to protect it from rapid and entire destruction; for in five years it had altered more than during 3400 years in Egypt. When it arrived it was a hard, granitic rock; at the end of the five years its surface had crumbled, and fragments of gravel had accumu-

lated at its base. In the same way, the stones in many buildings that have been exposed to the weather for several centuries have perceptibly decayed and crumbled.

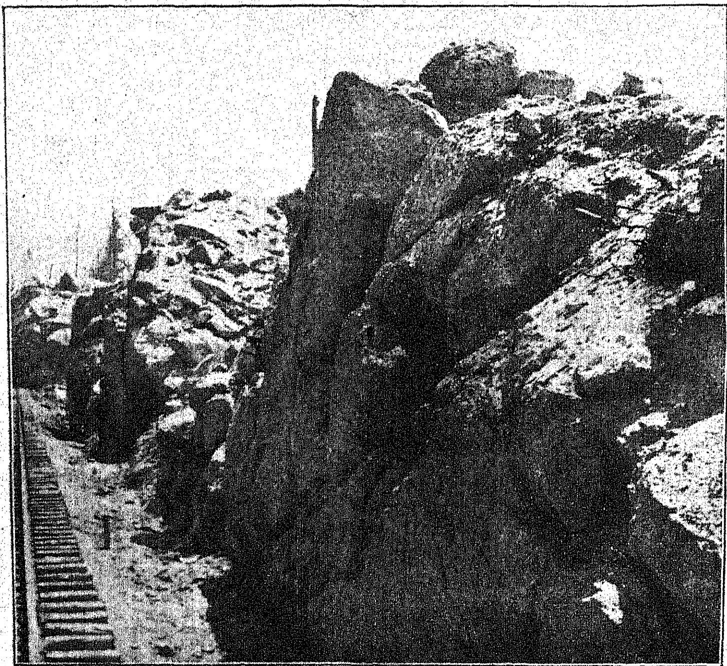

Fig. 47.

The crumbling of a granite ledge exposed to the weather in a railway cut. A partial soil accumulation with granite bowlders shown in middle of picture.

Presence of Water. — Let us suppose that we have a cliff of rock exposed to the air; it is a solid granite, formed of several very hard minerals which unite the

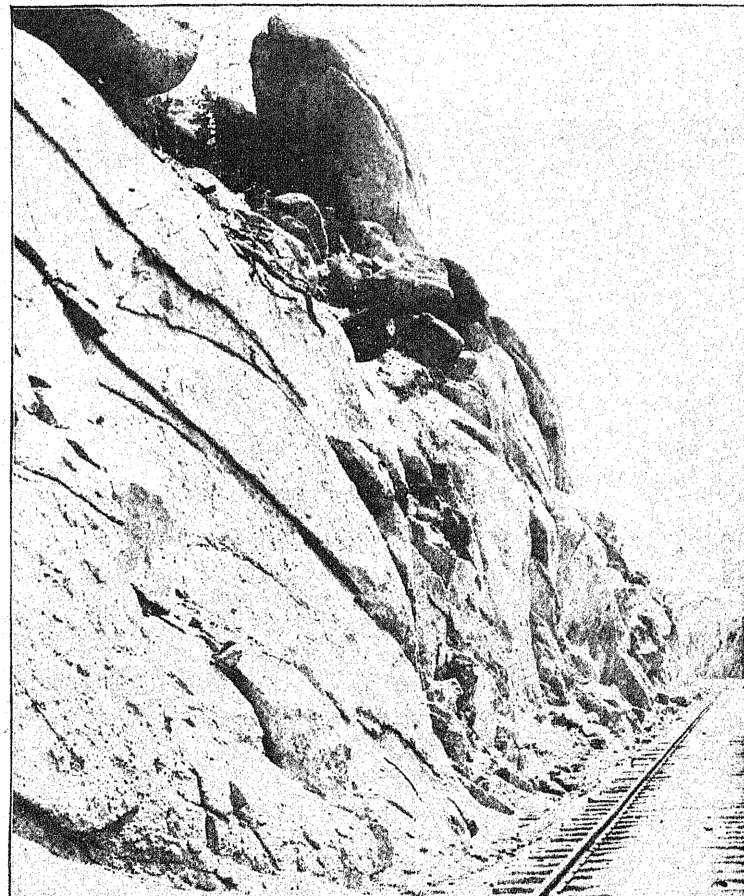

PLATE 3.

A granite ledge exposed in a railway cut. Disintegration shown by gravel accumulating at base, and by rough, crumbly surface of granite.

rock into a compact mass, though here and there joint planes cross it in several directions. It seems to be so hard that water could not enter it; yet, if our eyes were powerful enough, they would detect many minute crevices, through which water is constantly passing. Indeed, water is in every rock, and everywhere in the earth is slowly journeying along. Some beds (like the

FIG. 48.

Weathering of a rock of variable hardness. Soft layers removed, leaving harder parts standing in unstable position.

sandstones) are fairly porous, and in them wells will find an inexhaustible supply of water (see p. 147); but granites have fewer and smaller crevices, though even in these, water is always present in the very hearts of the blocks.

Mechanical Agents. — *Frost Action.* If our granite ledge is in a cold climate, like that of the northern

United States, where the temperature often falls below the freezing-point, the water contained in the crevices of the rocks must freeze. When water freezes, it increases in bulk; and therefore, if confined in a cavity, it exerts great pressure on the walls that enclose it. An iron ball or sphere, filled with freezing water and tightly sealed, will burst. The water that is in the rock cavities exerts like pressure, when frozen; and so, whenever the temperature of the earth's surface goes below the freezing-point, the action of the frost tears off tiny fragments of rock. This is one of the means by which rocks are made to slowly crumble.

On all bare ledges, and particularly upon exposed mountain tops (Fig. 55), this action of frost is very important, and the rocks rapidly disintegrate. In dry, desert countries, the surface strata do not contain water in appreciable quantity, and so here the action of frost is nearly absent; and in tropical lands, where the temperature never descends below the freezing-point, there is no frost action.

Effect of Heat. Another effect of temperature change, is that caused by the difference between day and night. When a rock is warmed it expands, and as it cools it contracts, so that when warm days are followed by cold nights, there is daily change. In some of the hot countries, the dark-colored rocks become so warm that it is painful to touch them; but

as soon as the sun sets, they cool rapidly and contract. This may cause the brittle minerals to snap at the surface, so that fragments fall off.

In early times, before mining was a science, this fact was utilized. Fires were built beside the rock which was to be mined, and this was then suddenly cooled. One may see this action of expansion and contraction, in any stone building that has burned. The great heat causes the rocks to splinter and crack, or the water that is thrown on the warmed walls, brings about the same result by producing contraction. On a much less noticeable scale, nature is constantly at work in the warmer lands, causing the rocks to crumble by this change of temperature.

Effect of Moisture and Dryness. Some rocks which are open to the air, crumble when dry, while others are made to crumble by the addition of water. Since rocks in exposed places are subjected to changes in the amount of water which they contain, they are often slowly caused to break, and fall into bits, by alternate wetting and drying.

Action of Plants. If we look at any granite ledge, we find the surface rough, and here and there little bits of gravel are seen, that by some means have been worked off from the solid rock. Upon its surface we find another agent of destruction in the form of plants, either lichens (Fig. 49) or mosses. Attempting to pick

up one of the lichens, we find it firmly attached to the stone, which as far as we can see is solid.

When we succeed in tearing off the lichen, we bring with it tiny fragments of the rock; and if we look where the plant grew, we shall see numerous root-like extensions entering minute crevices in the rock. As the plant grows, these "roots" increase in size, and as they do so, they pry off tiny fragments. One may see this same process upon nearly every ledge or bowlder, no matter of what kind. It may be that on some ledge we find a bush, or even a tree (Fig. 50), thrusting its roots along the cracks; and then, on a larger scale, we are enabled to see the action of growing plants in prying rocks apart.

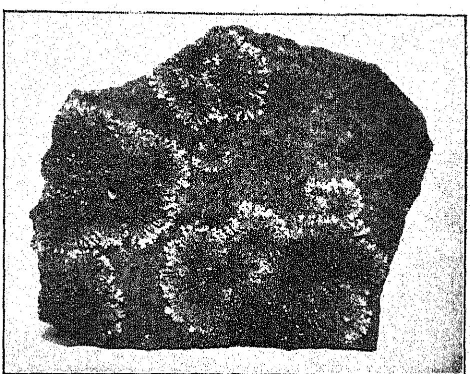

FIG. 49.
Rock with lichens upon its surface.

Myriads of roots of trees, shrubs, and grass, are engaged in this same task of pulverizing the rocky particles that form the soil. These roots may reach down to the solid rock, and entering this, help to break it up. When a tree is blown over (Fig. 51), as often

happens, it drags masses of soil and rock to the air, thus exposing them directly to the destructive action of the weather. This ever-acting work which plants are engaged in, is one of the most important of the agents of rock destruction.

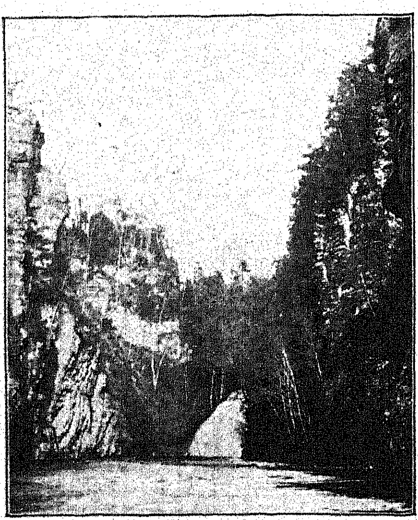

FIG. 50.

Trees growing in a gorge near Ithaca, N. Y. These are extending their roots into the shale, and prying off fragments.

Action of Burrowing Animals. Animals that bore into the ground are helping to pulverize the rock fragments. This is true of the prairie dog, the mole, and particularly of the earthworms, which live in such great numbers in the soil. Perhaps one of the most important groups of animals, in this respect, is that of the ants. Certainly this is so in some tropical countries, such as Brazil, where the earth is almost everywhere tunnelled by these busy and interesting creatures. Thus both animals and plants are constantly engaged in this work of grinding the rock fragments. Not only

do they pulverize the soil, but, by bringing earth to the surface, they render it more open to wasting agencies.

The processes of rock destruction so far considered may be called *mechanical,* in distinction from another

FIG. 51.
Forest tree overturned by storm wind. Quantities of soil dragged to the air entangled in the roots.

set that by *chemical* means coöperates with these to reduce the rock.

Chemical Agents. — *Percolating Water.* When rain falls upon the land, part of it enters the ground, and even passes into the rock itself. Pure rain water has little effect, but it ceases to be pure on beginning to

sink into the earth. The decaying leaves furnish it with substances that impart more power. When it falls, it contains oxygen; from the decaying vegetation, it takes carbonic acid gas, and perhaps some of the humic acids, and possibly alkaline substances. So it proceeds, armed with weapons of attack.

Some minerals, like quartz or calcite, it is able to dissolve, and the loss of the material thus taken away weakens the rock a little. Or it may find other minerals, like feldspar or hornblende, ready to change; then it causes a reaction to begin. When these changes have gone far enough, the rock crumbles, either because some of its minerals are removed by actual solution, or else because some have been made weak and soft, like clay, leaving the others unsupported, so that they must fall apart (Fig. 53).

This chemical process of oxidation, as it may be called, extends well down into the rocks, sometimes to a depth of several hundred feet. In the cuts made just outside the city of Washington, where they are grading some of the roads (and the same phenomenon may be observed in many other places), what appears to be a solid rock, with all the structure-lines present, has been so softened that it may be shovelled out like clay, which in reality, it is.

In many mines, an ore of one composition changes to another, as the mine descends below the zone of oxi-

dation. At Leadville, Colorado, for instance, the superficial ore was carbonate of lead; but below the line of oxidation, this becomes the sulphide, which is the real, unoxidized ore in this vein.

Action of Plants. Still another chemical action of rock-change is effected by plants. We have noted already that they give to percolating waters, certain substances needed to cause the changes which are going on in the rocks. They also do a *direct* chemical work. Every plant that grows in the soil is drawing up in its sap some mineral substances, which, when the plant is burned, enter into the ash. By this means, certain compounds are drawn in such abundance from the soil, that farmers are obliged to replace these forms of plant food by some kind of fertilizer.

Evidence of Chemical Changes. Returning to our granite ledge, we are able to see that this chemical change is also in progress there. If we break off a piece of the rock, we find the interior to be much fresher and harder than the surface portions, which are exposed to the air (Fig. 52). All through its mass, the quartz is clear, fresh, and glassy; but the feldspar is dulled and whitish, and there is a yellow stain of iron rust, caused by the leaching out of iron from the hornblende. A bowlder of granite, or of almost any crystalline rock, will show similar change; and upon almost any ledge these lessons in rock decay are illustrated.

The Soils. — *Residual Soil.* The chemical and mechanical agents of destruction go hand in hand; and in time, the result is the production of a soil-covering for the rock; provided that the winds and rains have not been able to wash it off as fast as formed. This class of soil, the most widespread in the world, is called a *residual soil* (Fig. 53), because it is made up of the residue of rock decay. It does not represent the entire product of the rock disintegration, because considerable has been removed in solution, either by the action of plants or of percolating waters. The residual soil often accumulates to a depth of a

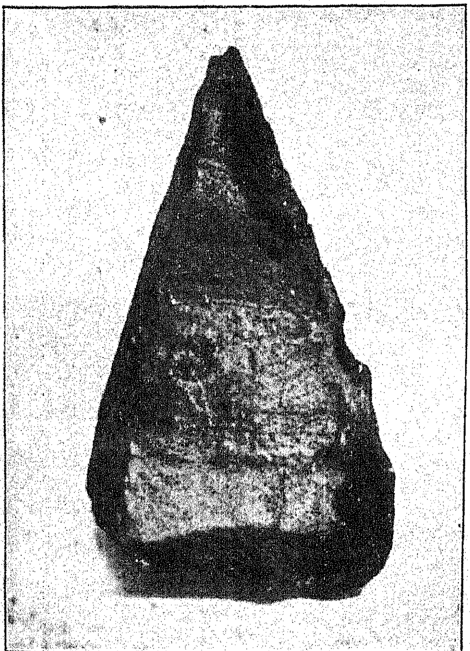

FIG. 52.

A sandstone rock, showing outer dark rim of decay, surrounding the fresh interior. Here calcite has been dissolved from the outer part, and iron rust has been deposited, staining the rim a dark red, while the color of the natural rock is nearly white.

score or more of feet; and in some places, as for instance in parts of Brazil, it has reached a depth of one or two hundred feet.

The section of residual soil shows very fine clay at the surface, where animals and plants, heat, cold, and water, have been longest at work. It grades downward into the fresh, intact rock, at first being mixed with large broken fragments (Figs. 53 and 54), and then changing to partly decayed rock in an undisturbed condition.

FIG. 53.
Photograph of a section of residual soil, showing rock fragments partly decayed in lower portion, and clayey soil above.

Other Soils. There are other kinds of soil besides these,—such as those formed by the wind which blows fine particles hither and thither, or by rivers which build deltas or floodplains, or by ice which causes an accumulation of glacial soils. It happens that in northern United States and Europe, the last is the common soil. It has been transported by great glaciers like that now covering Greenland, and is not the result of rock decay (p. 484).

Absence of Soils on Mountains. A residual soil-cover-

ing is possible only where at least a part of the decayed rock particles can lodge near the place where they have been formed. On a steep mountain slope, the winds and the rain quickly remove every particle that is small enough to be so carried away. In such places are always found either bare rock ledges, or else blocks of rock strewn over the surface (Fig. 55). Even

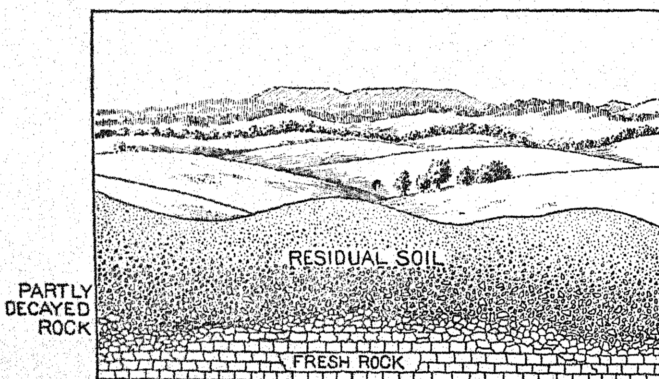

FIG. 54.
Diagram to illustrate formation of residual soil.

in hilly regions, where the slope is not so steep, the action of rain water may prevent the accumulation of soil, at least to any great depth.

Soil Protection. — When the soil becomes deep, it really protects the rock from rapid decay; for it forms a blanket which shuts out the heat of the sun, the action of frost, and of those plants whose roots are not long enough to reach down to the rock. In such

places the disintegration is only that of chemical change.

Forest Protection. — So, also, a tree-covering influences the rate of decay. Where there are trees, there is the deep action of roots, and there is always present a goodly supply of chemical substances in the layers of decaying vegetation through which the water must

Fig. 55.

Angular blocks near the top of Pikes Peak, Colorado, showing characteristic mountain surface strewn with frost-riven bowlders.

pass; but on the other hand, the forest keeps the soil from being removed either by the action of wind or of rain-wash, and so in this respect protects the rock (see Fig. 56, and compare this with Fig. 57). There are cases in France, where the removal of forests from hillsides has been followed by the disappearance of the soil, so that fertile farms have been transformed to barren wastes of rock.

In arid countries (Fig. 57), where the soil is dry and vegetation scanty, the wind sweeps over the land, and in some cases blows the soil from the rocks, leaving them constantly bare to the attack of the weather.

Formation of Talus. — Where cliffs rise, as they do near many streams, small particles fall from the rock and drop to the base. As these accumulate, they form a deposit of angular debris, called *talus* (Fig. 58). Sometimes the talus is very small, while in other cases it reaches well up on the sides of the cliff. As it grows upwards, it protects the rocks from further rapid decay; but before this, the naked rock face, constantly exposed to the weather, and kept bare by the aid of gravity, is a place of rapid rock waste.

FIG. 56.

A part of the Adirondacks near Lower Au Sable Lake, showing a surface protected by heavy forest. (Copyrighted, 1889, by S. R. Stoddard, Glens Falls, N. Y.)

Difference in Rate of Weathering. — There is a wide difference in the rate at which rocks weather under

varying conditions. Some easily decay, while others resist destruction; but every rock will crumble to some extent, no matter what its surface conditions and composition. Besides a difference in chemical durability, there is a variation in mechanical strength. Some

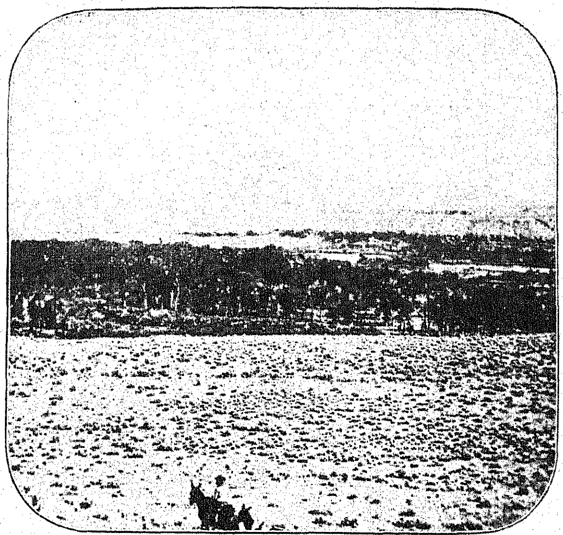

FIG. 57.

A characteristic arid land view (Crow Heart Butte, Wind River valley, Wyoming). Surface free from forest and almost free from vegetation, excepting near the rivers.

rocks are very porous, some very compact; and other conditions being equal, the more porous rock will decay faster than the more compact. Water follows the joints and crevices, and produces much more effect along these planes than elsewhere.

Not only are there these differences, but the amount of weathering varies with the climate and other causes. It seems certain that exposed rocks in cold regions decay with greater rapidity than those which are situated in the warm countries of the globe. This is due to the action of frost; but on the other hand, rocks decay to a greater depth in warm climates than in cold. The reason for this is, that in tropical lands, densely covered with forests, the water is warmer, and hence possesses higher chemical powers, which are also increased by the abundance of organic acids and alkalies furnished from the forest beds.

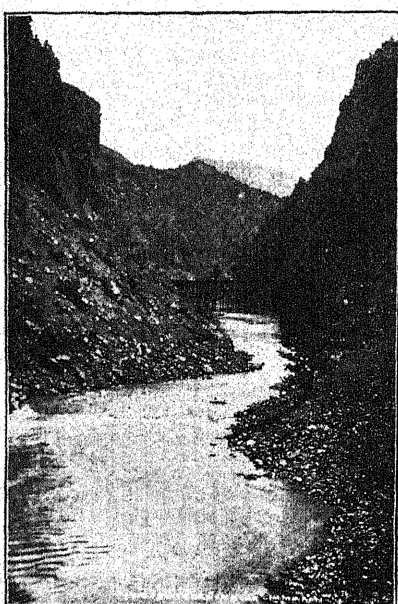

Fig. 58.

A talus slope in a river valley at the base of a high rock cliff.

On the other hand, in an arid region, since there is little water to enter the ground, there is naturally little change in the rock; and vegetation is so scanty that the effects of this agent are also lessened.

Any kind of rock finds protection in the soil and forest covering. Where bare rocks are exposed to the weather, the waste is most rapid. This finds illustration on lofty peaks, which reach into the colder regions of the upper air, and also upon the precipitous cliffs of many river gorges and mountain precipices.

Importance of Weathering. — The importance of weathering is great and varied. It causes the rock to crumble, and the surface of the land to melt down; and in many parts of the world it furnishes the soil; but if some of the decayed rock were not removed, this soil coating would soon so encumber and protect the rock, that the wearing down of the surface would be extremely slow.

In reality, weathering goes hand in hand with another process, which is commonly called *erosion*. By wind, stream, or ocean, and even in some places by ice, fragments of rock are removed and eventually deposited in the sea. Nature does not separate the processes of weathering and erosion. We divide them here merely for the purpose of clear description. Rocks decay, the fragments are in part removed, and the erosive agents, which carry them still further, aid in the reduction of the level of the land.

This combined action is denudation; and at all times the various agents coöperate in the task of lowering the level of the land and placing the waste in the sea.

In this work, weathering is the great preparer. It is of the first importance; for if rocks did not decay, not only would there be no soils formed, but the rain-born streams, flowing over bare rock, would not carry large quantities of sediment as now.

IMPORTANT AGENTS OF WEATHERING

	MECHANICAL.	CHEMICAL.
AIR.	Mechanical action included under erosion.	Direct effect of the air in promoting oxidation.
WATER.	Direct blow of rain. Freezing in crevices. Alternation from dry to wet condition.	Solution. Chemical change; oxidation.
CHANGES IN TEMPERATURE.	Change from warm to cold. Frost (combined with water).	Warming of percolating water.
PLANTS.	Action of roots on rock and in soil. Overturning of trees.	Solution in sap. Indirectly by furnishing substances to percolating water.
ANIMALS.	Pulverizing soil by burrowing through it and by taking it into their stomachs (earthworms). Bringing soil to the air (earthworms, ants, prairie dogs, and other burrowing animals).	Slight chemical action in stomach (earthworms). Indirectly, after death, by furnishing substances to percolating water which increase its chemical power.

CHAPTER VII

WIND EROSION

Use of the Word Erosion. — By the word *erosion*, as used here, is meant the wearing down of the land by agents which are able to remove substances. The agents that can do this are air, water (rain, river, lake, and ocean), and ice. The most important mode of erosive action is that of *corrasion*, which is mechanical. However, hand in hand with this, goes the chemical work of *corrosion*. No attempt is made to separate these, for they are most intimately related. Since materials are removed by erosion and deposited by the same agencies, these processes of destruction and construction are considered together.

Mode of Wind Action. — The wind is an important agent in geological change. It ruffles the surface of lakes and oceans, producing waves and currents which bring about numerous changes. It aids in the distribution of seeds, so that many plants readily find it possible to spread themselves widely over the land.

When a violent volcanic eruption occurs, and great quantities of dust-like ash are thrown into the air, the wind bears it far and wide, strewing it over the land and ocean. Ash thus transported, has fallen at distances of scores and even hundreds of miles from the place of eruption.

Another notable action of the wind is that of blowing the finer rock and soil particles hither and thither, distributing them over the land. This action of the wind is particularly noticeable, (1) on the sea or lake shore; (2) in dry countries.

In most parts of the moist regions of the earth the ground is usually damp, and is protected from the wind by a covering of vegetation. Since this is true of the climate in which men chiefly dwell, we are not accustomed to consider the wind as a prominent agent of erosion.

On the tops of mountains, where the wind is fierce, and where, because of the cold, vegetation is either very scanty or entirely absent (Fig. 55), the wind is of service in removing the finer particles of rock decay. The same is true in arid and desert lands, where little or no vegetation covers the soil to protect it from the blasts (Figs. 59 and 66). Here, on every windy day, the surface soil is in motion, and at times clouds of sand rise in the air, shutting from view even the neighboring hills. These blinding "sandstorms" are well

known from the frequent descriptions of them by travellers in the Sahara, where they sometimes endanger life.

Sand Dunes. — By this process the fine particles are drifted about, and in places where the drift accumulates, sand hills or *sand dunes* are built (Fig. 59). The soil of the surface is in such frequent movement, that even the desert plants cannot find a foothold.

FIG. 59.

The desert of Sahara. Practically no vegetation. Sand dunes in the background.

Extensive deposits of sand and clayey sand are sometimes made in these places; and in parts of northern China, deep deposits of such a wind-blown soil, called *loess* (Fig. 60), cover a wide area. Of course all these deposits are fine in texture, never being coarser than sand, because the wind can carry only the lighter bits of rock.

Upon most sandy sea-coasts, the wind finds it possible to move the sand from the beach and drive it inland, forming hummocky hills or sand dunes (Figs. 61 and 62). In this manner, by the aid of the waves, the wind builds many islands near the coast. The process is simply this: first the water throws up a bar to the height reached by the greatest storm wave, and then the wind builds these higher still (Fig. 62). The sandy islands from Sandy Hook southwards, and some of those on the New England coast, have been formed in this way. In New England this is particularly the case along the shores of Long Island and Cape Cod.

FIG. 60.
Walls of loess in China.

One of the most interesting cases of the formation of islands by accumulation of blown sand, is found in the Bermudas. Here for countless ages corals have lived and died furnishing their limy shells to the waves, which have ground them into bits on the beach. Then the wind has gathered these fragments into hills above the reach of the waves, and nearly all of the Bermudas are built of this coral sand (Figs. 62 and 63).

FIG. 61.

Sand dunes, Cape Ann, Mass., covering the site of a farm now buried, because a forest which protected it was removed.

FIG. 62.

A beach in the Bermuda Islands, with wind-blown coral sand hills in the background.

Where the conditions are especially favorable, the blown sand may move inland. The removal of a forest will often allow the wind to blow the sand inland so that not only is the site of the forest covered by sand dunes, but fertile farms, formerly protected, are submerged beneath the accumulation (Fig. 61). On the coast of France, the sand dunes have moved in-

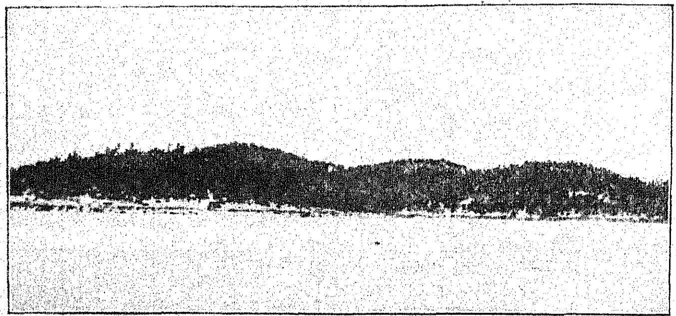

Fig. 63.

Hills in Bermuda Islands formed of blown coral sand now cemented into a hard coral rock.

ward, not only covering farms, but destroying villages. Likewise on the shore of Lake Michigan, there is a sand dune region that is even now destroying forests (Fig. 64). The French government is preventing the inland march of the sand by planting trees which check the action of the wind.

When blown by the wind the sand is assorted into layers of varying coarseness. This results from the

fact that the wind blows with variable velocity. When violent, coarse particles are removed and deposited, while in more quiet weather only the finer fragments can be moved. Besides this, the layers are tilted at various angles according to the direction of the

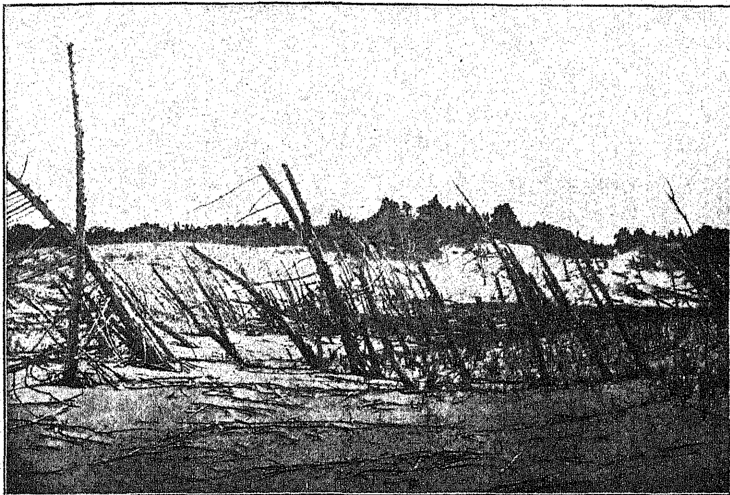

FIG. 64.

A forest being destroyed by the encroachment of sand dunes near the shore of Lake Michigan.

wind, which is also variable. Therefore the wind-drift structure in a deposit of blown sand is very complex, with layers of different texture set at various angles (Fig. 65).

Erosive Action.—Not only is sand moved by the air, but even rocks are destroyed when they stand in

the path of sand-laden winds. In the arts, sand is violently thrown against glass by a blast of air, chipping it and producing ground glass. Nature acts in the same way on a more moderate scale. On the sandy island of Monomoy, on the southern side of Cape Cod, Massachusetts, the glass in the fishermen's cottages has been made into ground glass, by the constant chipping

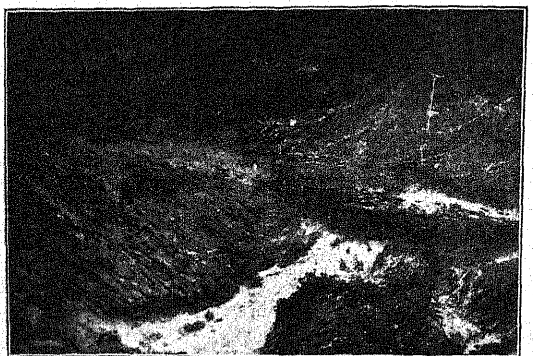

FIG. 65.

Section in wind-blown sand at Bermuda, showing the layers set at various angles.

which it has received from the sand that is driven by the fierce ocean winds. It takes years to do this, but it bears witness to the power of the sand as an agent of erosion.

So also in parts of the West, where sand is constantly moving, it is smoothing and polishing the rocks by its continual action. Cliffs that are exposed to the wind are also eaten back and etched by it; and we often

see a softer layer cut into a series of caves, because the wind action is more effective in carving the soft layer (Figs. 66 and 91). Not merely are fragments thrown against the cliffs, but also the removal of particles prepared by weathering, and nearly ready to fall, is promoted by the wind action. In arid regions,

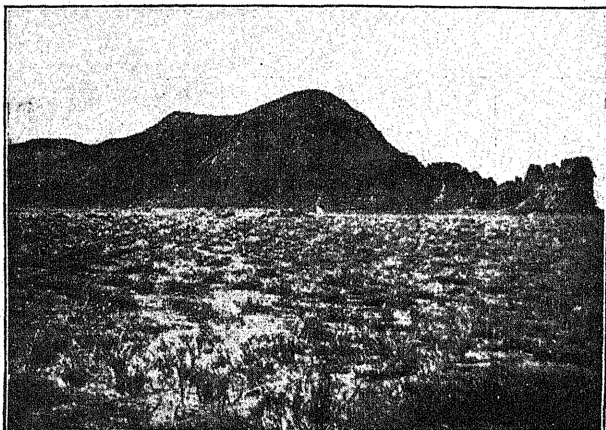

FIG. 66.

A view in the arid lands, showing scanty vegetation, and a cliff open to the attack of the wind. The cliff is sculptured by this action, and the wind has prevented a talus from accumulating at its base.

where rain and the ordinary agents of weathering have little power, the wind becomes one of the most important causes of destruction.

Not only is sand accumulated on the land, but it is often blown into the lake, river, and sea. From the river it may enter the ocean, and thus aid in the

accumulation of sediment that is forming in its bed. Along many coasts situated near dry lands, the off-shore winds are directly contributing sediment to the sea. Indeed, everywhere, this source of sediment from the land is one of the ways in which ocean deposits are being derived.

ACTION OF THE WIND

	Erosion.	Deposition.
On Mountains.	Violent mountain winds remove all small particles.	Winds remove, but are too violent for deposit.
On Moist Lands.	Forest and other plant protection prevents erosion.	Deposit possible only in rare places, where for some reason plant protection is absent, and a supply of sand near by.
In Arid Lands.	Constant movement of soil. Cliffs and exposed rocks, chipped and cut. Rocks stripped of soil and kept bare.	Formation of sand beds; of sand dunes; of loess. Material furnished to the sea.
On the Sea-Coast.	Wave-formed sand, ground finer by friction when moved by wind. Lifted by the air, and hence exposed to weather and plant action. Sand-blast action also present.	Sand dunes formed. In coöperation with waves, islands built. Beaches raised higher. Materials mainly taken from the sea and added to the land; but the reverse action sometimes present.

CHAPTER VIII

UNDERGROUND WATER

General Importance. — When rain falls, some sinks into the ground, some is returned to the air by evaporation, and some flows off at the surface to swell the rivers. That part which enters the ground commences a journey, perhaps of great length and occupying much time. During this, work of various kinds may be done, and it is this which we will now consider.

As the water sinks into the soil or rocks, most of it chooses the easiest course, and perhaps actually prepares a path for itself. It may go on deep down into the earth and undertake a journey of great length, perhaps returning to the surface at some distant point, possibly after having remained for ages beneath the ground. In such a case, when the water returns, its temperature is usually high, possibly even above the boiling-point.

While a certain part of the underground water goes on these long journeys, much of it undertakes only a short passage, almost at the very surface, and soon reappears,

either in the form of a spring or by gently oozing from the soil or rock. We may see the latter on the face of any cliff after the melting of the winter snow; the former mode of return is familiar to all. The underground water changes the minerals (p. 117), and at the end of its journey always brings to the surface a certain small amount of rock material in solution. This

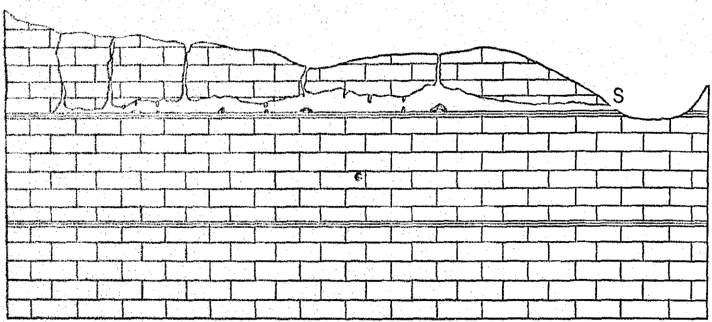

FIG. 67.

Diagram to illustrate formation of limestone caves. Water enters through sinkholes and after passing on an underground journey in the caverns, reappears at the surface as a spring (*s*).

robs the soil of some of its constituents, and adds them to the river, which in turn carries them to the sea.

Limestone Caves. — Water sinking into the ground will follow the easiest channel open to it; and as there are numerous natural breaks in the rocks, these commonly serve as passageways. If the rock which the water meets is a soluble one, like limestone, these natural channels may be slowly enlarged (Fig. 67). By

this action caves may be formed; and as the water flows along, constantly receiving tributaries, a maze of underground caverns may result, as is so well illustrated in the noted Mammoth Cave of Kentucky (Fig. 68), and the caverns of Luray in Virginia.

These channels may be occupied by actual subterranean rivers, draining into some surface stream which they enter in the form of springs. Limestone strata are often honeycombed by these caverns. The water of the surface drains towards a saucer-like depression or *sink-hole*. In the centre of this it sinks into the earth to commence its underground journey, which may be many miles in length. Such rivers, as well as percolating water, are enlarging the caves by solution; but some of the greater streams of the subterranean passageways, are also deepening the caves by mechanical wear of erosion.

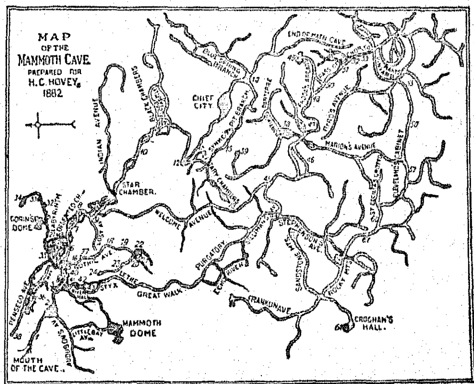

FIG. 68.

Map to show maze of subterranean channels in Mammoth Cave region.

Of the thousands of such caverns which pierce the limestone rock, only a very few have been opened to the eye of man, for entrance to most of them is difficult or even impossible. As the surface of the land melts down by denudation, these subterranean chambers may be partly or entirely opened to the air (Fig. 69). In some, like the Mammoth, fish are found in the underground river.

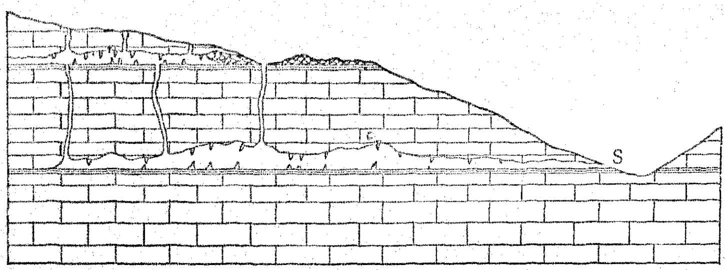

Fig. 69.

Diagram to illustrate exposure of caverns to the air by melting down of surface by denudation. This shows the same section as Fig. 67, after denudation has lowered the surface. In the meantime a lower cavern has been developed.

The limestone is dissolved by water charged with carbonic acid gas; but as it enters the cave through the limestone roof, some of this gas escapes and the water is then forced to deposit a portion of its dissolved carbonate of lime (Fig. 35). This may form pendent *stalactites*, or, dropping to the floor, build *stalagmites* (Fig. 70). The downward growth of the stalactite may meet the rising stalagmite, forming a

passage of water through some of the porous materials to more impervious layers; as, for instance, when water passes through sand beds to underlying rock, or a layer of clay. Trickling along the surface of this impervious mass, the water lubricates it and causes a slipping plane, over which, if ready, the upper mass of earth may slide. During every rain there is some motion of this nature among the surface particles of soil; and on many hillsides we may find little scars formed where masses of earth have slipped so recently that vegetation has not grown over the place from which the earth has moved.

Upon steep mountain sides, a landslide or avalanche may start high up near the top, and rush downward with terrific violence, gathering force and size as it descends, and ploughing a path of destruction even through a dense forest. As it falls, it causes a violent wind which is sometimes strong enough to overturn houses. Landslips occur, too, where streams or ocean waves are undermining cliffs (Fig. 71).

Noticeable though they are, landslips really accomplish less than slower actions which we do not commonly notice; for these are constantly at work all over the earth, while the landslide, though violent, is local and comparatively rare. Of more widespread importance than avalanches, is the minute sliding of the soil particles which are rendered slippery during rains

(Fig. 76). These are really minute landslips of infinitesimal degree. A single one is minute and unimportant, but the countless millions caused by every rain, represent a great sum total in the course of time.

Springs. — A part of the underground water, after a short passage, returns to the air along some channel. Often this flow is sufficiently permanent to form a spring, either one always welling, or one that has water only in moist seasons. Every one is familiar with these, and there are far more than we commonly see; for upon many hillsides are damp, boggy places, which, if the vegetation were removed, would become permanent springs.

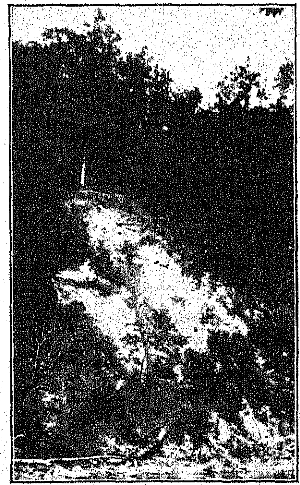

Fig. 71.

Fresh scar on a cliff in a stream valley, where the creek has caused a slip by undermining.

There are several conditions under which springs may be formed. Where the underground rivers that are shaping caverns appear at the surface, there are true springs, often large and permanent (Figs. 67 and 69). Again, a break or fissure in the rocks, may reach down to a layer containing water whose temperature is high; and where this reaches the surface (Fig. 72),

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passage of water through some of the porous materials to more impervious layers; as, for instance, when water passes through sand beds to underlying rock, or a layer of clay. Trickling along the surface of this impervious mass, the water lubricates it and causes a slipping plane, over which, if ready, the upper mass of earth may slide. During every rain there is some motion of this nature among the surface particles of soil; and on many hillsides we may find little scars formed where masses of earth have slipped so recently that vegetation has not grown over the place from which the earth has moved.

Upon steep mountain sides, a landslide or avalanche may start high up near the top, and rush downward with terrific violence, gathering force and size as it descends, and ploughing a path of destruction even through a dense forest. As it falls, it causes a violent wind which is sometimes strong enough to overturn houses. Landslips occur, too, where streams or ocean waves are undermining cliffs (Fig. 71).

Noticeable though they are, landslips really accomplish less than slower actions which we do not commonly notice; for these are constantly at work all over the earth, while the landslide, though violent, is local and comparatively rare. Of more widespread importance than avalanches, is the minute sliding of the soil particles which are rendered slippery during rains

(Fig. 76). These are really minute landslips of infinitesimal degree. A single one is minute and unimportant, but the countless millions caused by every rain, represent a great sum total in the course of time.

Springs. — A part of the underground water, after a short passage, returns to the air along some channel. Often this flow is sufficiently permanent to form a spring, either one always welling, or one that has water only in moist seasons. Every one is familiar with these, and there are far more than we commonly see; for upon many hillsides are damp, boggy places, which, if the vegetation were removed, would become permanent springs.

FIG. 71.

Fresh scar on a cliff in a stream valley, where the creek has caused a slip by undermining.

There are several conditions under which springs may be formed. Where the underground rivers that are shaping caverns appear at the surface, there are true springs, often large and permanent (Figs. 67 and 69). Again, a break or fissure in the rocks, may reach down to a layer containing water whose temperature is high; and where this reaches the surface (Fig. 72),

warm water may escape, causing a *hot spring*. These warm springs may have substances in solution which give them medicinal properties. Such *mineral waters* are not only drunk at the spot, but often bottled and widely sold.

In its underground journey, water may pass along the minor cracks near the surface, until an outlet to the air is found. Then a spring is produced. Quarrymen often encounter such springs as they quarry a rock from its bed; and at the base of cliffs they are also common. Many of the springs that abound in the hilly parts of New England are of this character.

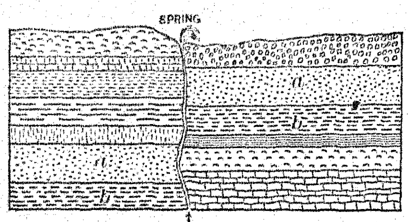

FIG. 72.

Diagram to show conditions existing where a spring ascends through a fault plane.

Perhaps the most common kind of spring in the northern United States, is that which depends upon differences of rock texture. For instance, if a layer of sand rests on clay, the less dense sandy rock allows the water to pass freely through it; but when the clay is reached, further progress is partly checked. If the clay layer is inclined, the water runs along the surface, perhaps coming out to the air on a hillside (Fig. 73).

Whatever the class or origin of springs, it is to be

noticed that they all illustrate the passage of water through rocks; a passage which, in every case, sometimes by changing and sometimes by dissolving some of the minerals, leaves the rock slightly modified. The springs, and the water which is slowly seeping through the rocks, give to the stream a load of dissolved mineral to be carried from the land to the seas.

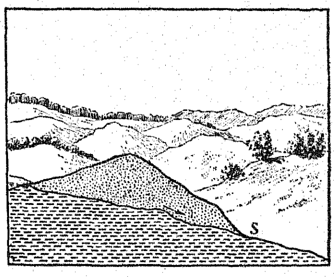

Fig. 73.

Diagram to illustrate formation of a spring on a hillside where porous strata overlay impervious rock.

Artesian Wells. — While water is percolating through all the rocks, its passage through some is easier than through others. A loose stratum, composed of sand grains, is more permeable than a dense one made of fine grains of clay. In many parts of the world this difference gives rise to peculiar conditions, which are of value to man in furnishing a supply of pure water from deep within the earth.

Where first found, in the Province of Artois in France (Fig. 74), the conditions were as follows: a sandy layer of rock had been so bent that the two ends extended to the air, while the lower portion was deep in the earth. Above and below it were layers of impervious rock. Where the sandy stratum was

exposed at the surface, water easily entered and passed down into the earth, being enclosed there by the impervious rocks above and below, and thus prevented from either rising or descending. By the time it reached the centre of the depression, the water was under considerable pressure from the weight of the water contained in the upper ends of the layer. When this water-bearing stratum was pierced by a boring, the water rushed to the surface, forming an *artesian well.*

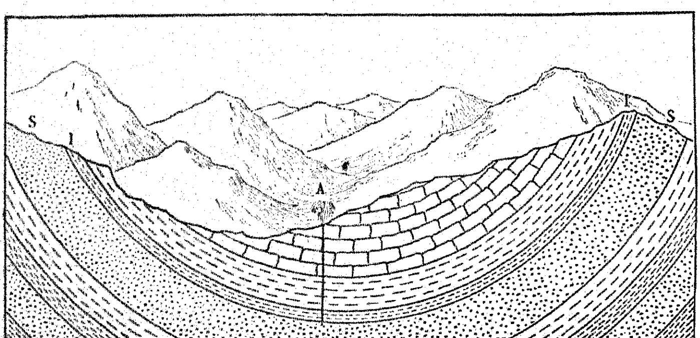

FIG. 74.

Section showing conditions favoring formation of artesian wells (*A*), where the strata are bent in a U-shaped manner. *S*, porous layer. *I*, *I*, impervious strata.

For an artesian well, it is necessary to have all the above conditions excepting the double slope of the water-bearing layer, which may or may not be present. In New Jersey, South Dakota, Texas, and many other parts of the world, a sandy layer of this kind dips into

the earth, constantly becoming deeper (Fig. 75). A well, or a thousand wells, bored down to this, will find water which rises nearly to the height of the place where the layer first enters the ground.

So the conditions necessary for an artesian well are four: (1) there must be a porous stratum; (2) this must be overlaid and underlaid by impervious layers;

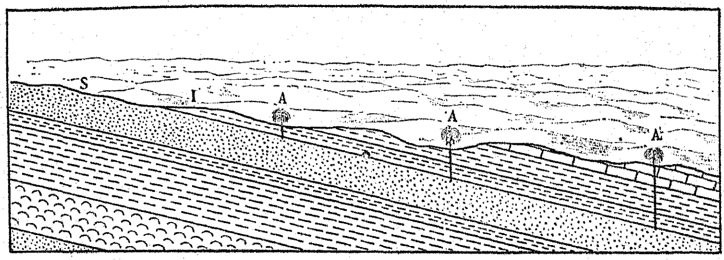

FIG. 75.

Occurrence of artesian water where the rocks dip into the earth. *S*, porous sandy layer. *I*, *I*, impervious strata. *A*, *A*, *A*, artesian wells.

(3) these must descend into the earth; and (4) the place where the well is bored must be lower than that where the porous layer crops out at the surface, and gets its supply of water. Several of the cities of eastern Texas obtain their water supplies from wells which reach down to such layers, many miles from the place where the water enters them. The same is true also in other parts of the West where artesian water is used in irrigation.

ACTION OF UNDERGROUND WATER

Movement.	Results Accomplished.
Sinks into the earth.	Dissolves and changes minerals. Weakens rocks. Carves channel-ways.
Rises in hot springs.	Brings mineral substances to the surface in mineral springs.
Rises in springs.	Brings mineral matter to the surface.[1] Furnishes water supply.
Follows subterranean channel-ways in limestone.	Carves caverns. Deposits stalactites and stalagmites. Reaches the surface in the form of springs.
Passes between impervious layers in a porous stratum.	This condition gives rise to the important artesian wells.

[1] This is true of all underground water which reaches the surface.

CHAPTER IX

RIVER EROSION

Rain Erosion. — The work of erosion begins at the very moment when the raindrop strikes the earth, provided it touches the soil. We may see this on any summer day when a few drops of rain are falling upon a dusty road. The drops strike the dust and send a little of it into the air, thus doing some mechanical work. As the rain increases, small rills begin to form, and the water of these runs off, and finally becomes part of a stream. Between the raindrop and the river no distinct line can be drawn.

In forest-covered regions the soil is protected from the action of rain at the surface; and unless the rains are very heavy, little work of erosion is done until the drops have gathered into streams; but on unprotected ground, as we may see on a ploughed field, or a road, or anywhere in dry countries, where there is little vegetation, the rain cuts into the earth even before it has gathered into rivulets.

The very drops, and then the little rills, remove

some of the soil, particularly if they are operating on a steep incline. As a result of rain erosion, the soil in many places is washed away as fast as it forms. This action causes a constant migration of the soil particles down the hillside (Fig. 76); and at the base, where the slope decreases, this product of the *rain-wash* gathers into a deep accumulation. In many parts of the arid West, one may see stone walls partly buried beneath this wash, which has accumulated during the short time that they have been standing.

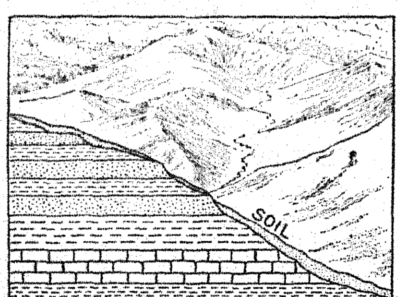

Fig. 76.

Diagram to illustrate creeping of soil down the hillside. Formed by weathering, it gradually moves down, accumulating near the base of the hill.

Nearly everywhere this rain-wash is one of the important means by which rivers are given sediment to bear away, and it is also one of the means by which the surface of the land is slowly worn down. That this is so, every one can see for himself by watching the streams during a heavy rain, especially if the water enters the river after passing over roads and fields. The tiny rills become laden with mud, and soon the river is transformed to a muddy torrent.

Where the soil is a clay, it may be cut into very remarkable and fantastic columns by the action of rain erosion (Fig. 77). This is particularly true in arid regions, as in the Bad Lands of South Dakota, and many other parts of the West (Plate 4). These

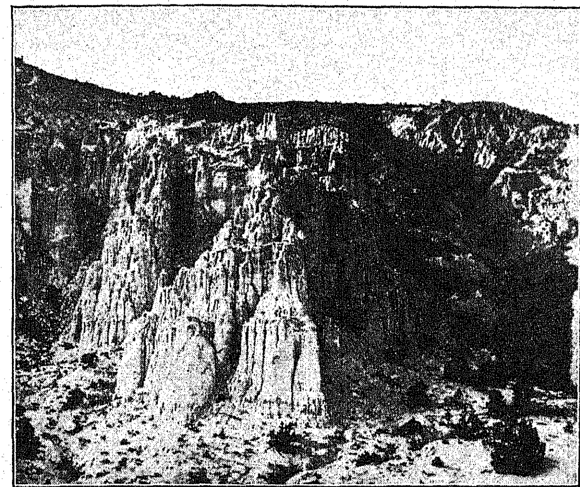

FIG. 77.

Earth columns in New Mexico. Caused by rain-sculpturing of clay beds.

rain-carved columns are often capped and protected by hard fragments, which allow them to stand up to a height of several score of feet, even though they are composed of a soft clay. Every rain, though these are rare in the dry country of the West, sculptures the clay a little more. The scenery in these rain-sculpt-

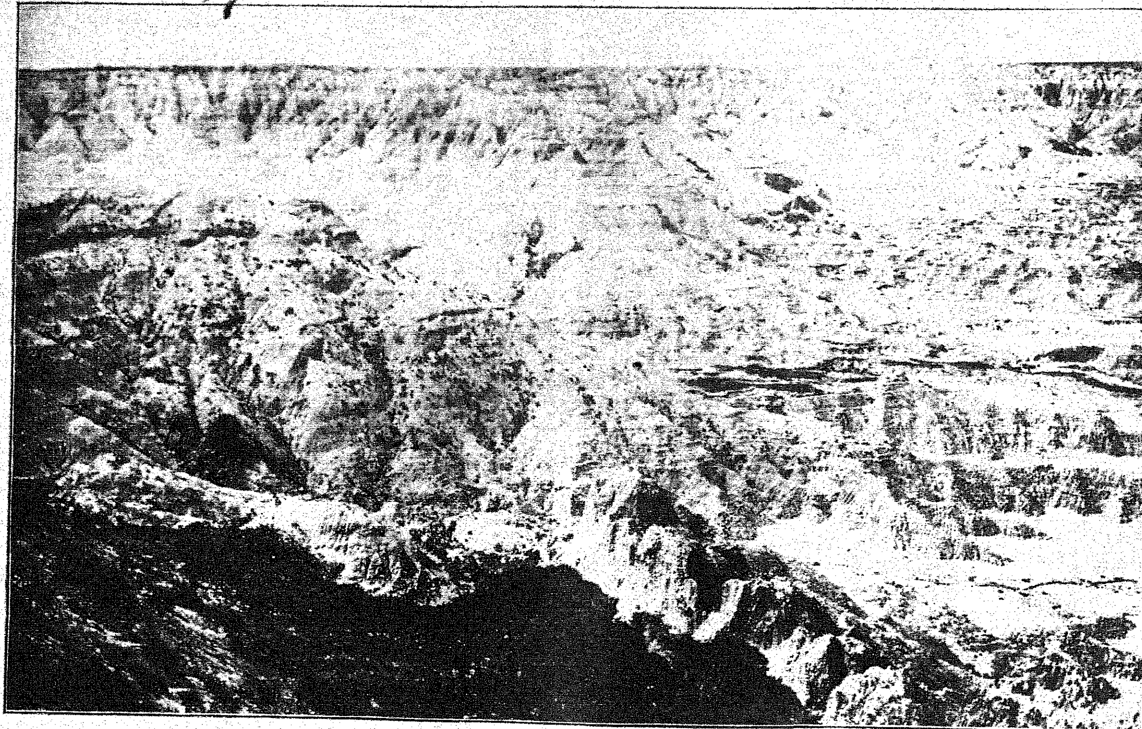

PLATE 4.

The rain-sculptured clay lands in the Bad Land region of South Dakota.

ured clay lands is weird and unique; and the surface is so irregular that it is almost impassable (Plate 4).

On a rather extraordinary scale, this is an illustration of what the rain is everywhere doing in a less noticeable way. Generally the rain action is less intense in its effect in moist countries; but even this picturesque action is not confined to dry regions, for on a small scale we may see it on nearly every clayey surface. In parts of Mississippi, the rains have so sculptured the clay lands of the abandoned plantations, from which the forest has been removed, that portions of the state resemble the true Bad Lands of the West.

Supply of River Water.—A much more striking work of erosion is accomplished by the rain after it has gathered to form rivers. Passing off toward the sea, it gathers into streams, which carve channels for themselves. During a freshet or heavy rain, the river rises and becomes a torrent, and then perhaps sinks to a mere trickling stream, or even runs dry.

If rivers depended entirely upon the *direct* gathering of the rain, they would become flooded during and immediately after each rain storm, and then would rapidly diminish until the next. But in fact, the river valley in most regions always holds water, particularly if the river is large. The reason for this is found in the constant supply from under ground, and from the litter of plant remains strewn over the forest floor. A part of

each rain is reserved as a *permanent* supply for the rivers; and so for their perennial supply, streams depend in great degree upon springs.

Where forests have been removed, the water flows off more readily, and less is left to be supplied from the springs after the rains are over. Hence in forested regions, rivers are moderately permanent in size and volume, while in those sections which have been deforested, they swell to violent torrents after every heavy rain, and then, if small, may quickly become mere dry channels.

Chemical Action. — Although it was once believed that valleys were formed by other means, and then occupied by rivers, we now know that the streams have shaped their own valleys. Most of the river valleys in the world have been carved by the action of the waters that occupy them, aided by weathering. They do this work by the combination of two different processes, — chemical and mechanical.

River water is always at work in a chemical way; and just as underground water dissolves minerals in its passage through the rocks, so the surface water, as it flows over its rocky bed, is always taking some mineral matter into solution. The amount thus dissolved depends partly upon the materials that the water carries, and partly upon the rock over which it flows. When very impure with organic materials, the

water may dissolve with some rapidity, particularly if it is flowing over a relatively soluble rock, like a limestone; but even a granite would be slightly dissolved by ordinary river water.

Even when conditions are favorable, the action of solution is slight when compared with the mechanical work of water. This is well illustrated in the Niagara River where it flows out of Lake Erie. Here it has almost no valley, although in a part of its course it flows over an easily dissolved limestone; but in the same period of time, below the falls, a gorge has been carved out by mechanical action. As the river leaves Lake Erie, it is clear and free from sediment, and must work by solution alone; that it is achieving something is shown by the roughened surface of the limestone blocks just above the falls; but how slight this action is, may be understood from the fact that the deepening of the valley has been almost imperceptible.

An analysis of any river water, will show much mineral matter in solution; but it is not to be supposed that the river has taken all of this from its channel. Most of it has come from springs and other sources of underground water. Therefore, while not coming from the channel proper, it is derived from the area which the stream drains, and every bit that is thus removed, serves to widen or deepen the river valley. That portion which is taken from the channel,

only deepens the *river bed*, but that which seeps in from the ground, serves to lower the general surface; and this is one of the ways in which river valleys are broadened.

We look at the clear river water and hardly imagine that it holds a load of mineral in solution; yet analysis proves this, and in the course of a year a good-sized river conveys a prodigious burden of dissolved substances to the sea. For instance, each year the Arkansas River carries past Little Rock, about 6,800,000 tons of dissolved mineral, and this is by no means exceptional. The substances that are found to be most abundant in this river, are salt, carbonate of lime, carbonate of soda, and silica.

It has been estimated upon a fairly satisfactory basis, that over 8,000,000 tons of mineral matter are carried to the sea each year from the British Isles. At this rate (assuming the material to have come equally from all parts of the islands), solution alone would lower the whole surface of the British Isles one foot in about 13,000 years. So in the course of ages this work of water is an important one.

Mechanical Action. — *Cutting Tools.* Pure water, flowing over a hard rock, produces no perceptible effect upon its channel by mechanical action. The tools with which rivers deepen their valleys are the rock fragments which they carry (Plate 5). As these are dragged

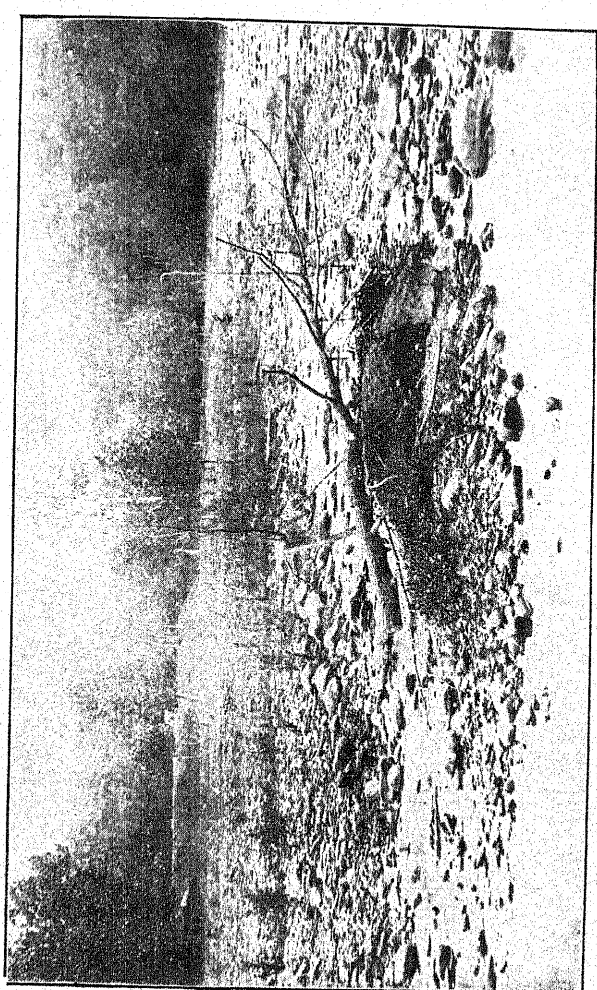

PLATE 5.

Pebbly bed of a stream in Central New York, showing tools used by rivers. The pebbles and bowlders are rolled down stream in flood times.

or whirled along, they wear one against the other, and against the bed of the river, all the time grinding off other fragments. By this means, angular pebbles have their corners worn off and rounded, and after a short journey, become greatly reduced in size, perhaps being entirely ground to sand and clay. In the course of this reduction, the rocks in the river bed are battered away, and the valley deepened. Even the finer particles of sand and clay rasp at the rock, so that in time, by this cause also, the valley bottom may be dug deeper.

The supply of these cutting tools comes in part from the softer rocks over which the river flows; but it is chiefly furnished by the crumbling cliffs and valley sides, and by the washing action of the rain. A river, ordinarily clear, may become a muddy torrent after a heavy rain, or in the spring when the snow quickly melts. So the supply of cutting materials varies from day to day, and one river may be heavily laden while another is clear; or one may transport pebbles while another carries only fine mud or sand, the size depending upon the velocity of the water and the source of the materials.

In some cases rivers are furnished with so much sediment that they cannot remove it all, but must deposit some and *build up* their valleys instead of cutting them deeper. The Platte, for instance, because of this over-

burdened condition, is not engaged in deepening its channel. The most favorable condition of sediment for rapid valley deepening is that of a heavy load, always present, but never exceeding the power of the river to carry it. Such streams are continuously at work carving into the rock. No better illustration of this can be found than that remarkable river which has excavated the Colorado Cañon (see p. 170).

Intermittent Work. A second point of importance in valley deepening is the slope of the land, for the velocity of flowing water increases with the slope. Thus, with a steep incline, the mountain torrents are able to carry even large bowlders, and with them to cut easily into their beds.

Even with a given slope, a river may vary in velocity according to the amount of water carried. We may see this illustrated in almost any stream of moderate size. Ordinarily, even though the slope be great, the water flows along at a moderate rate; but when the floods come it is transformed into a raging torrent, when bridges are in danger of destruction (compare Frontispiece and Plate 6). The river is then a rapid worker, and it is safe to say that at such times streams do more valley deepening in a few hours or days, than is done in the remaining months of quiet water. With their cutting tools, rivers carve intermittently, now rapidly and again slowly or scarcely at all.

PLATE 6.

Ithaca Falls, N. Y. Same view as Frontispiece in dry season. A small amount of water in the creek used for manufacturing.

Valley Deepening. The kind of rock over which the river flows, is another cause for variation in the rate of valley deepening. Other things being equal, a stream wears a soft stratum more easily than a hard one. The stream does not cut in all parts of its bed with equal ease, but may be engaged in building a bar in one place,

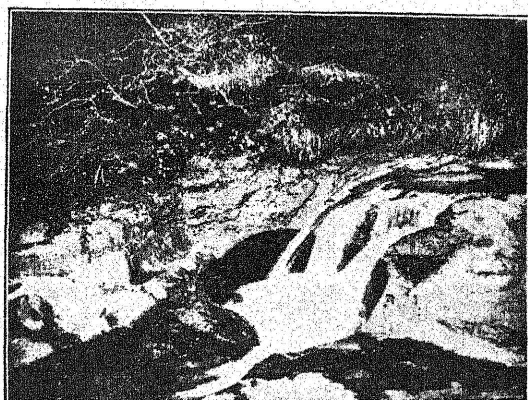

FIG. 78.

Pot-hole being scoured out by stream action.

while just above or below this it is eroding a deep gorge. In the beds of rivers we often find saucer or kettle shaped holes, commonly called *pot-holes* (Fig. 78). These are formed where the current favors rapid deepening by constantly whirling pebbles around, and thus grinding out saucer-like depressions. The reasons for these differences in cutting, are many and local, and in

almost any stream bed one may see the variations and understand their cause.

Again, the work of valley deepening is almost confined to the narrow line occupied by the stream, for the erosive action of the river itself is mainly confined to its bed. It does a little more than this, for every

FIG. 79.

A stream, by meandering, cutting into its bank, so that it is necessary to protect it by posts.

stream meanders about, and in the course of time, may abandon one channel and pursue another. A raft of logs or a small avalanche may be the means of sending it over against the opposite bank. So it changes about, now eating at the base of a cliff on one side, and again, having abandoned this course, it cuts at the

opposite bank, and slowly broadens its valley (Figs. 71 and 79). When confined within steeply rising banks of hard rock, this broadening action of the river is limited.

Coöperation of Weathering. Still, if nothing but the river were at work, the valley would be narrow and trench-like (Fig. 80). A gorge would necessarily be the result as the river cut deeper and deeper. Here is where river erosion and weathering go hand in hand. The cliffs crumble in the air, the soil is washed into the streams, and slowly the sides of the gorge wear back, and the banks change from angular cliffs to rounded slopes. If the stream is deepening its valley, it may cut its channel more rapidly than the slow action of weathering can broaden it; and then the river valley remains a gorge (Fig. 80); but if the stream has been long at work, the action of weathering will have operated to widen the valley until the gorge condition is destroyed.

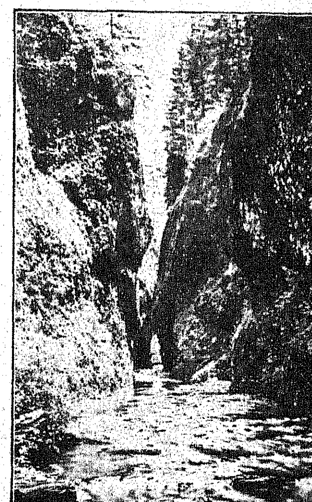

FIG. 80.

A very narrow gorge cut so rapidly by the stream that it has not widened greatly. The cutting is being done without much broadening by river meandering.

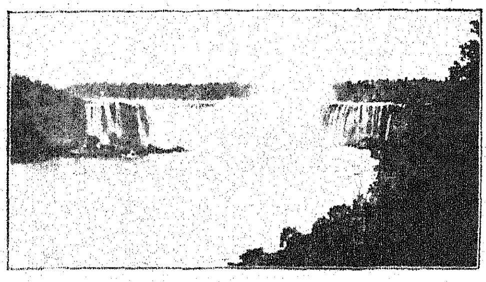

Fig. 81.

A general view of the Horseshoe Falls of Niagara.

So a broad and gently sloping river valley represents greater age or longer period of work than the narrow, angular gorge. Where weathering is slow, as in the arid regions of the West, even valleys of considerable age are angular, and rugged gorges or cañons are common. Gorges are also numerous in mountains, because the torrent flowing in a steep valley deepens it faster than it is widened by weathering.

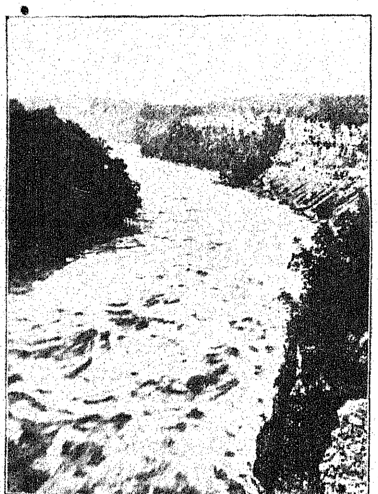

Fig. 82.

Niagara gorge below the falls. The hard limestone is seen at the top of the cliff, while the softer shales form a more gentle slope below.

The river is the channel in which the surplus rainfall flows away. In its course it either picks up or otherwise receives sediment by the aid of which it deepens its valley, being aided in this work by a certain slight

amount of direct solution. Weathering prepares the bulk of the sediment, and the river removes it. The stream cuts its valley deeper, and weathering, because of its power to decay rocks, and because the stream is ready to remove the fragments thus given to it, continually broadens the channel.

Waterfalls. — As a stream cuts through the rocks, it often finds layers of different hardness. The softer ones it grooves more rapidly than the harder, and in this way may locally transform itself to a series of rapids, or even a direct waterfall. Most of the waterfalls of the world are due to variable rate of work in layers of different hardness. Of these we may take Niagara as a type (Fig. 81).

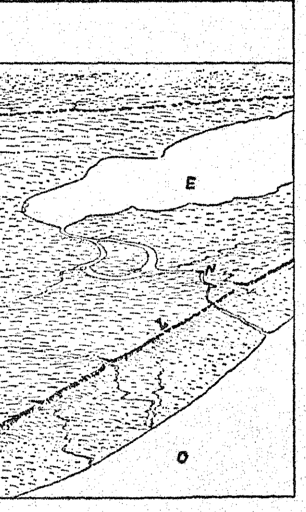

Fig. 83.

Bird's-eye view of Niagara River. *E*, Lake Erie; *O*, Lake Ontario; *N*, Niagara Falls; *L*, the bluff, at Lewistown, caused by the hard limestone bed, and over which the water fell to form the first Niagara Falls.

Here the rock strata are nearly horizontal, and at the crest of the Falls there is a hard limestone layer, beneath which are soft shales (Fig. 82). This limestone cap resists the action of weather and water, but the soft shale is easily worn

PLATE 7.

Taughannock Falls, near Lake Cayuga, N. Y. This also illustrates the relation of stream cutting in the channel and weathering which broadens the valley.

away. So the mighty cataract leaps from this hard shelf of limestone and dashes against the soft shale, which it constantly removes. Little by little the shale is worn out from beneath the limestone, which the weight of the water then breaks away; but the continued stretch of this hard limestone layer maintains the fall always at about the same height.

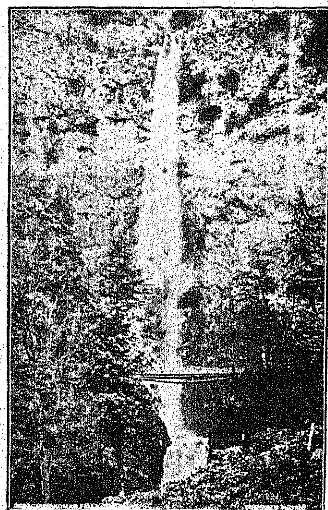

FIG. 84.
Multonomah Falls, Oregon, a fall of great height (824 feet) which has not cut a perceptible valley.

During less than one-half of a century, the Horseshoe Fall has moved back more than two hundred feet, and there is evidence that Niagara Falls have been at nearly all parts of the gorge (Fig. 82). Every year the falls have moved a short distance up stream, until they are now seven miles from the starting-point, where they existed when first the waters of Lake Erie were drained out over the bluff at Lewiston (Fig. 83). Even now each year witnesses that same slow retreat, and the outline of the falls has changed perceptibly since first seen by the white man.

What is true of Niagara is equally true of many

of the large and small falls of Europe and America, — such, for instance, as those of central New York (Frontispiece and Plate 7), St. Anthony and Minnehaha, in Minnesota, and thousands of others[1] (Fig. 84).

The Colorado Cañon. — The most marvellous river valley in the world is that of the Colorado of the West (Figs. 85 and 86). This river flows through steeply rising, rock-bound walls, over a grade of nearly eight feet to the mile, always carrying large quantities of water and sediment, and at times becoming a raging torrent, which sweeps along not only finer materials, but pebbles and bowlders. It is still deepening its valley at a rapid rate, and for three hundred miles flows in a cañon, which it has carved, whose walls rise to a height of from one thousand to several

FIG. 85.

A scene in the deeper part of the Colorado Cañon.

[1] While this is the most common cause of waterfalls, it must not be supposed that it is the only one. Space prevents further consideration of the subject here; but a somewhat more complete statement may be found in the author's *Elementary Physical Geography*.

thousand feet (in places more than a mile) above the river bed (Fig. 86). Not only is the plateau cut by this marvellous cañon, but it is also trenched by hundreds of less magnitude.

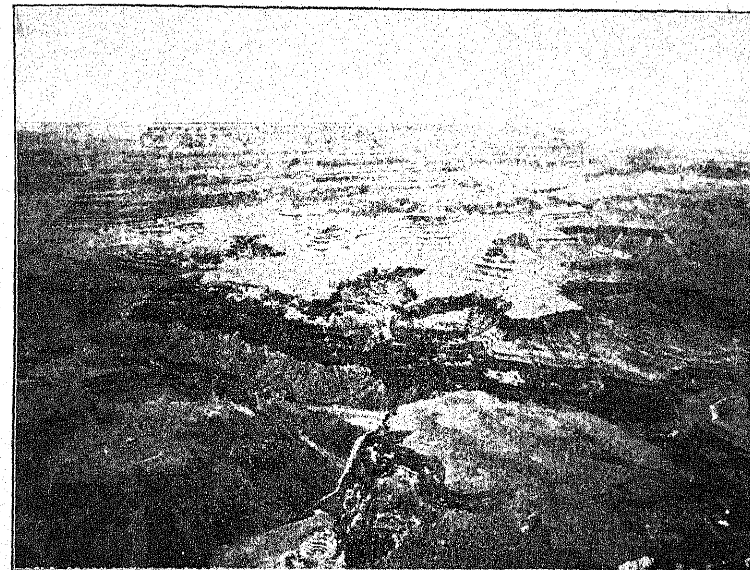

Fig. 86.

A general view of a part of the Colorado Cañon, showing the sculpturing of the general surface.

In many parts of the world, similar but smaller examples of river erosion are found; but while wonderful and impressive, the Colorado is hardly more so than a *broad* river valley with gently sloping sides; for if we consider that once the rocks extended entirely

across, we see that to form a wide, gently sloping valley would require a much longer time than to carve out a steep-sided gorge, even a Colorado. In the gorge the river has cut the rocks apart; in the broad valley, not only has this been done, but the slow action of weathering has been able to melt back the valley sides and form rounded slopes (Fig. 87).

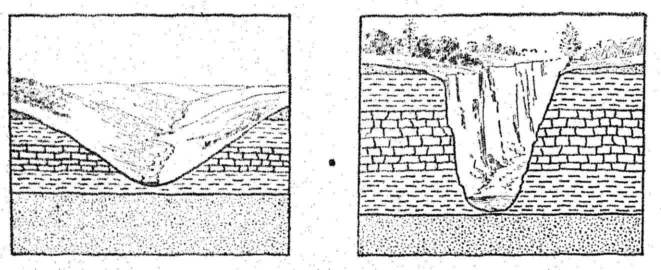

FIG. 87.

Diagram to show difference in amount of rock removed in narrow and broad valleys.

River work of valley deepening is rapid compared with that of weathering which, because of the slowness of its action, escapes common notice. But even the relatively rapid work of river erosion was long overlooked, and it was thought that rivers had little share in the formation of the valleys that they occupy. It was believed that they represented great rents in the earth or else the action of powerful ocean waves. Now, we know that most of the gorges and deep valleys have been formed by the rivers.

EROSIVE WORK OF RIVERS

	Chemical.	Mechanical.
Underground Water.	Dissolves mineral substances, broadens and lowers the valley, and furnishes the river with mineral matter in solution.	A very slight effect.
Rain Water.	Supplies the underground water. Here, and also at the surface, does some chemical work.	Carves soft rocks. Slowly wears the harder strata. Furnishes the streams with sediment.
River Water.	Slowly dissolves the rocks of the stream bed, particularly the more soluble.	Moves the cutting tools supplied it, and wears them down, at the same time eating into its bed. By meandering, broadens its valley somewhat. Sometimes unable to remove all the load. Works intermittently according to velocity. Rate of work also varies with nature of the rock. Forms waterfalls, gorges, cañons, and even broad valleys.
	By means of the intimate coöperation of these two processes, valleys are deepened and broadened, and most river valleys of the earth are thus formed. In connection with the valley formation much material is removed from the land and carried to the sea.	

CHAPTER X

RIVER AND LAKE DEPOSITS

River Deposits

Transportation of Sediment. — By actual measurement, the quantity of material carried mechanically by the Mississippi, and dumped into the Gulf of Mexico, amounts annually to about 200,000,000 tons. This, if accumulated on a space with an area of a square mile, would form a prismatic block 268 feet high. In addition to this great mass of sediment, the Mississippi is also carrying a load of chemically dissolved mineral. Thus the drainage area of the Mississippi is slowly lowered, and the Gulf of Mexico filled. The great delta at the mouth of the Mississippi (Fig. 97) shows how important is this work of carrying and filling.

The Arkansas, which annually carries about 6,800,000 tons in solution past Little Rock, is also carrying about 21,400,000 tons of sediment. This represents an amount removed by the river, which, in the course of about 9400 years, is equal to the removal of a foot

of rock from every part of the Arkansas drainage area. In reality, the loss is not so uniform. At some places only a few inches would be removed, while in others the surface would be lowered several feet.

Aside from that carried in solution, the load of rock materials is transported either in the suspended condition, as may be seen in any river during a flood, or else by dragging along the bottom. In the upper or torrential part of a stream valley, the material carried is usually coarse pieces of rock, and these decrease in size toward the mouth, where, because the slope is less, only the finer fragments can be moved.

In a large river, the sediment does not all go down together in a single journey, but portions halt here and there, perhaps to form a bar, perhaps to enter into the structure of the floodplain, where they may stay for a long time; and then, as the river in meandering changes its course again, may be picked up and made to resume their journey.

The sediment goes by steps with numerous halts, usually brief, but occasionally of long duration. Notwithstanding all temporary stops, during the course of ages the progress is plainly seaward. The ocean, the goal towards which the sediment is tending, with rivers as the carriers, is made the dumping-ground for the waste of the land. Aside from the great mass of sediment thus given to the sea, and strewn over its

bottom, there are other kinds of river deposits that need explanation.

Alluvial Fans or Cones (Cone Deltas). — When a river emerges from a mountain valley upon a plateau, its slope often quickly changes; and if it carries much sediment, some of this must be deposited. This is done

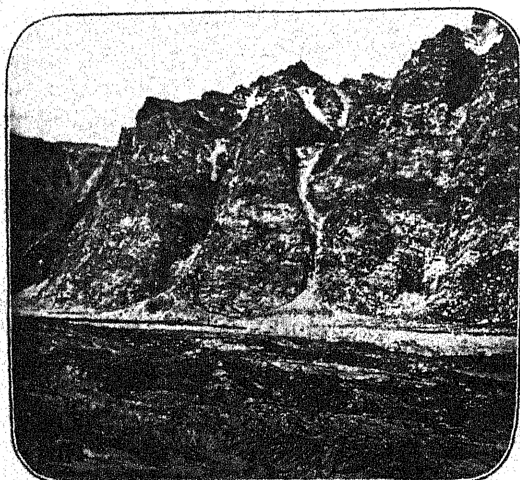

FIG. 88.

Alluvial cones at the base of small mountain valleys.

at the outlet of the mountain valley, and an accumulation is built up at the mountain base (Fig. 88). This deposit, which is a part of a cone, with its apex up stream, spreads out fan-shaped. The river flows over its surface in different channels, so that in the course of time, it deposits sediment on all parts of the slope

(Fig. 89). The alluvial fan is particularly well developed in mountain districts, although we also find it, in less distinct form, in hilly regions, where streams with steep slopes emerge upon a valley plain. Similar accumulations are often seen near the base of a cliff, where the talus locally assumes cone shapes (Fig. 90).

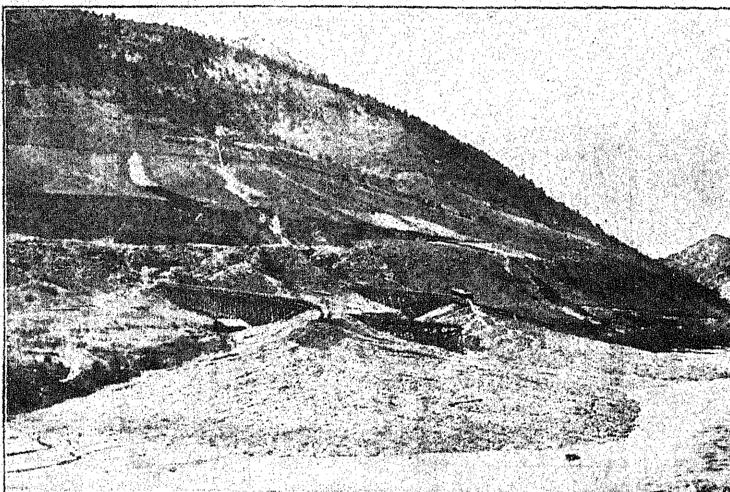

FIG. 89.

Alluvial cones formed by washing gravel for gold. Gravel carried in the sluices is dropped when the current emerges from them, and hence loses its velocity.

Bars. — Where an obstruction exists in a sediment-laden stream, bars may be built in the eddy of the current (Fig. 91), or formed opposite the mouth of a tributary. These bars are constantly altering their form and position; and if the current changes, may

be entirely destroyed. Sometimes they are built so high and so large that the stream is divided into two channels, one of which is ultimately abandoned.

Floodplains. — Rivers which are not enclosed between rock walls, are often bounded by plains which they themselves have constructed. When they rise in floods and

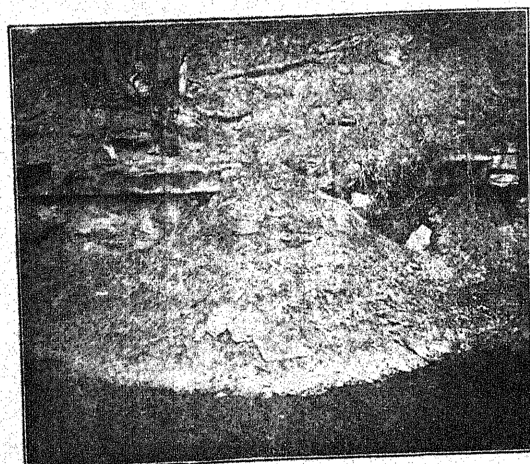

FIG. 90.

A small alluvial fan forming part of a talus at the base of a shale precipice.

overflow their banks (Fig. 92), the muddy torrents spread out on either side of the channel. In these places, being shallower, and more retarded by friction against the bottom, the water loses some of its velocity and is unable to carry as much sediment as it can in the deeper and more swiftly flowing channel

portion. So the floods deposit a layer of sediment, and in time these accumulations build up a plain, whose surface is below the level of the flood water, but above that of the ordinary stages of the river.

Among mountains, floodplains may be made of coarse gravel deposits; but in the gently sloping lower

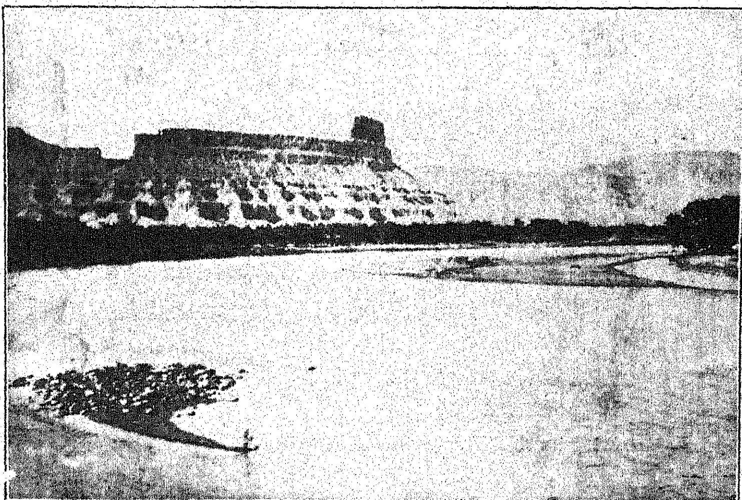

FIG. 91.

Bars in Green River, Wyoming. Gunnison Butte in background.

reaches of the river, the plains are almost invariably composed of very fine sediment. In the greater rivers of the world, the floodplain may be a broad and fertile tract of land, so valuable for agriculture that expensive earthworks are thrown up, as levees, to prevent

the river from overflowing it and submerging the cultivated sections.

Terraces. — *Terraces* are narrow plains parallel to the river, ending in an abrupt descent on the side toward the stream. Sometimes the river flood, by reaching different heights with the varying volume of water, builds such narrow plains on either side of the river at different levels. While some river terraces are made in this way, many, and perhaps most, have been caused by excavation (Fig. 93). A river in cutting down through clay or gravel, changes its course by meandering, and is now on one side of the valley and now on the other (Figs. 71 and 79). So in excavating it leaves a series of terrace steps.

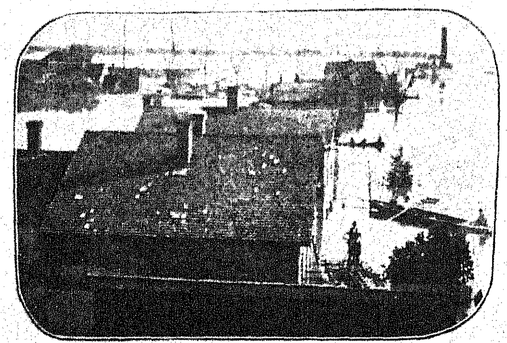

FIG. 92.
River overflowing its floodplain, New Albany, Indiana.

Deltas. — Where a river enters a lake, its flow is suddenly checked, and the sediment cannot be carried far beyond the mouth. This causes a deposit to be commenced beneath the lake waters, which in course

of time, grows upward to the very surface, when it becomes a plain. As additional deposits are made, they cause this delta plain to grow outward into the lake. In some places lakes have been entirely filled by this action, while others have been separated by the growth of deltas across them (Plate 8).

This deposit is called a delta, and over it the river

Fig. 93.

Terraces of excavation in the Madison valley, Montana.

flows, often by several mouths. This is due to the fact that the delta is a nearly level plain, over which the river water cannot all flow through a single channel, as it does where the slope is more abrupt in the ordinary valley above.

As the floods of the river overspread the delta (Fig. 94) through the various mouths, and deposit sediment upon it, both the elevation of the delta and

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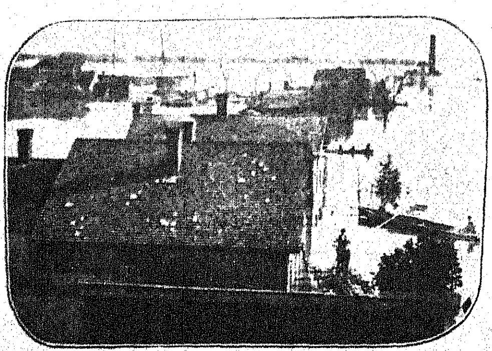

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PLATE 8.

Swiss map showing division of lake into two parts by growth of deltas from opposite sides, at Interlaken.

that of the bottom of the stream are raised above the level of the water in which it is made, so that the river is often obliged to change its course from one part of the plain to another. This is very well shown in the delta of the Yellow River of China, which frequently

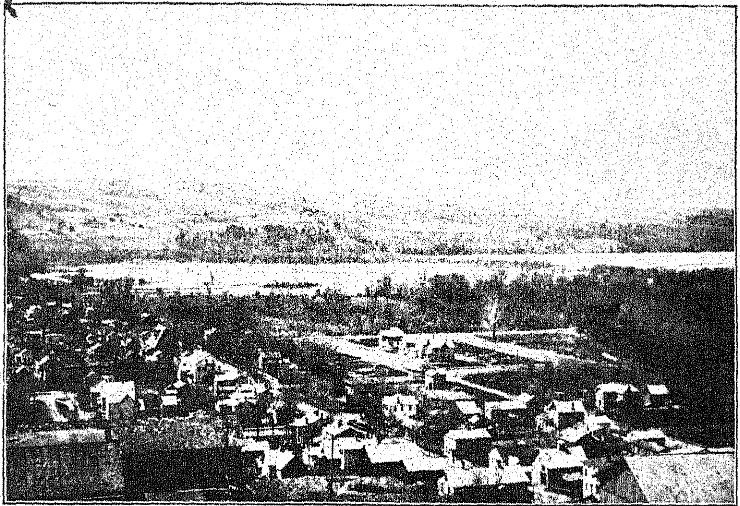


Fig. 94.
Delta in Lake Cayuga, Ithaca, N. Y. (see Fig. 96), overflowed by flood water.

changes its mouth during flood, not only shifting its course to a place many miles away, but causing a terrible destruction of life and property.

This branching and changing of the river mouth, builds a triangular shaped deposit, which in the Nile so closely resembles the Greek letter Δ (Fig. 95), that

this name is given to all similar deposits at stream mouths. Generally, though not invariably, the delta preserves a triangular form. Very often the typical outline is destroyed by the action of waves or currents, particularly opposite the mouths of small streams entering lakes.

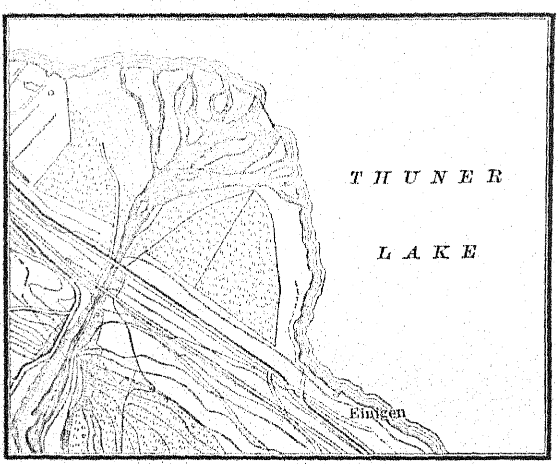


FIG. 95.
A typical delta form in Switzerland.

Deltas are present in nearly every lake into which good-sized streams flow (Fig. 96); but the largest and most famous of the world are found at the mouths of rivers which enter the sea. Such mighty streams as the Nile, the Mississippi (Fig. 97), the Yellow, the Indus, etc., have immense deltas, which are steadily

and even rapidly growing outward. On the other hand, many large rivers, such as the Amazon, have no deltas.

In some cases the absence of deltas is due to the fact that ocean waves, tides, and currents, remove the sediment about as fast as it is brought to the sea, and

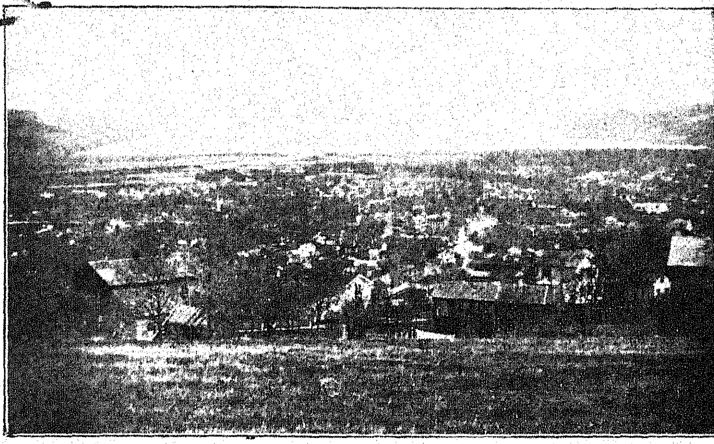


FIG. 96.

A delta at the head of Lake Cayuga upon which the town of Ithaca, N. Y. is built. (See also Fig. 94.)

hence prevent its accumulation near the river mouth. In other cases this absence is due to a general lack of sediment transported by the streams. If the sea reaches a great depth opposite the mouth of the river, the development of a delta is also retarded; and in many cases, one of the chief causes for the absence of a

delta, is the fact that the ocean bottom near the river mouth is sinking, so that the rate of sediment deposit is not able to raise the bottom as fast as it settles, even though the river is large and muddy.

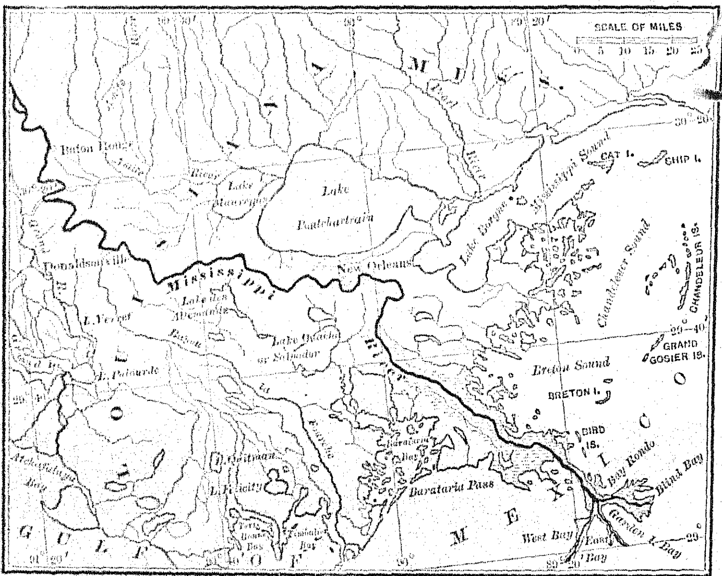


FIG. 97.

A map of the Mississippi delta. Lands subjected to overflow marked by dashes.

In some cases, as for instance along the coast north of Florida, the rivers, instead of entering the sea over deltas, have their mouths in bays or estuaries. This is due to the fact that the land has been so recently lowered that the ocean enters the river valley (Plate 13).

DISPOSAL OF THE RIVER LOAD

	MECHANICAL.	CHEMICAL.
IN THE RIVER.	Deposits clay, sand, or pebbles in its bed, sometimes as a sheet, on the bottom, but more commonly as bars. These may remain for long periods of time.	Deposits of carbonate of lime or other substance sometimes precipitated in river bed when the water is evaporated.
ON THE LAND.	Where the slope is rapidly decreased, alluvial fans are built. Along the margins of many streams the sediment is made into floodplains.	Sometimes, in arid regions, streams carrying much alkali, on spreading out over neighboring lowlands leaves a thin film of these substances on the surface.
IN LAKES.	Builds deltas. Furnishes sediment that is strewn over the lake bottom. Ultimately these accumulations fill the lakes (see p. 188).	Supplies various substances to lakes. These become noticeable in lakes without outlets. Then, after awhile, the water may become so impure that some of the substances must be deposited.
IN THE SEA.	Builds deltas. Furnishes sediment that is distributed over the bottom by waves and currents.	Carries to the ocean the carbonate of lime needed by animals, and adds other substances to the ocean water.

Lakes

Cause and Condition. — In most cases, lakes are formed by some obstruction in the course of a stream, and they act as filters which strain out the sediment from the rivers that enter them. Sometimes lakes are formed between mountains where a mountain barrier rises across a river valley; but more commonly they are due to some less pronounced dam, one of the commonest being a deposit of clay or gravel left by glaciers (Fig. 117).

Usually lakes are fresh and have outlets to the sea; but in some of the arid countries, they may be enclosed and cut off from the ocean, because evaporation is greater than the rainfall, and hence the water cannot rise to the rim of the basin. Lakes which have no outlet, like the Great Salt Lake, are usually saline (p. 193).

Filling with Sediment. — Rivers that enter the lakes, if they only have time enough, will, by their sediment deposit, destroy the largest lakes, whatever the cause of these may be. Every particle of sediment brought by them settles in the quiet lake water; and in course of time this will fill the basin, provided the outlet is not cut down meanwhile. The coarser sediment builds deltas out into the lake (Figs. 94–96); the finer particles are strewn over the bottom.

This filling action is aided by the waves that beat against the shore. These form cliffs by cutting into the rocky coasts, and build beaches on which the pebbles are worn backward and forward, and ground into finer bits. The gentle currents carry these away and deposit them over the lake floor. In the larger lakes, the erosive action of waves and the carrying power of currents, resemble the work done in the sea. This subject may therefore be left for the present (p. 237).

Animal Deposits. — Animals inhabit lakes, and sometimes bear an important share in the filling process.

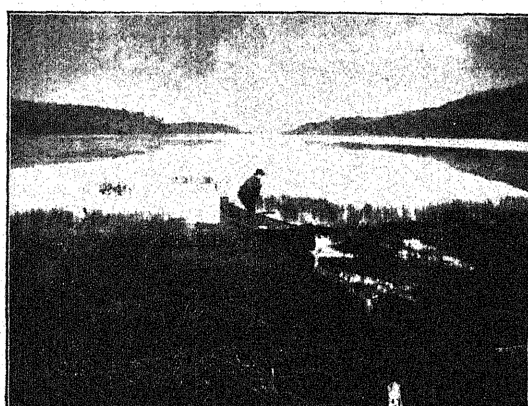


FIG. 98.

Long Lake in the Adirondacks bounded by a swampy shore. Vegetation encroaching upon it. (Copyrighted, 1888, by S. R. Stoddard, Glens Falls, N. Y.)

Where very little sediment is supplied, as in small shallow lakes, layers of animal remains may be deposited to form *marl* or some other earth of organic origin.

Plant Deposits. — Plants also aid in lake destruction, particularly in the last stages. As the water becomes shallow, vegetation commences to encroach upon the lake (Fig. 98). The life and death of these plan[illegible] permits the accumulation of vegetable deposits whi[illegible] eventually may become many feet in depth. [illegible] Florida lakes are being destroyed almost entire[illegible]

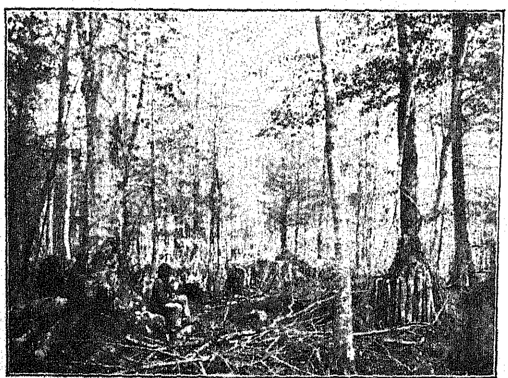


FIG. 99.

A view in Dismal Swamp.

this means, for no sediment enters them, and the shores are dense swamps, while the bottom is a muck of vegetable origin. Dismal Swamp (Fig. 99) is another illustration of an extensive swamp associated with lake waters, Lake Drummond being enveloped in the swamp.

Peat Bogs. — In the northern states, many of the smaller lakes have been filled and are now transformed

to swamps, while not a few are almost completely choked. In this region may be seen every stage in the final destruction of lakes by the aid of plant growth.

One form of plant is of particular importance in this respect. A moss, the sphagnum, grows luxuriantly the the shores of these tiny ponds and lakelets; and

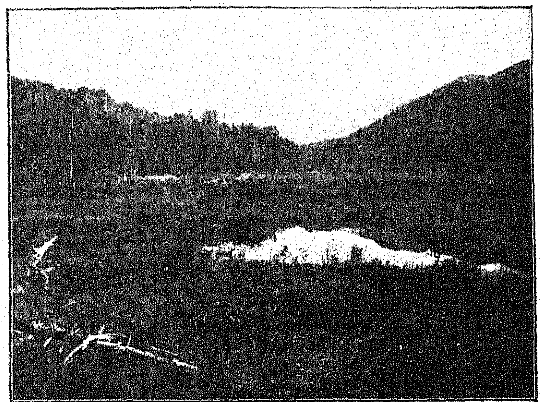


FIG. 100.

A peat bog in the Adirondacks with a pond enclosed — the last remnant of the former lake. (Copyrighted, 1888, by S. R. Stoddard, Glens Falls, N.Y.)

by its life and death, builds a bog which is sometimes several feet in depth. Little by little it narrows the area of water (Fig. 100) and finally destroys it, in the last stage becoming a quaking bog, owing to the fact that the peat is growing over the surface of the remaining muddy water (Fig. 101). Such bogs are dangerous because the moss is growing as a thin sheet over water,

or a watery muck, into which one may sink. Ireland and Scotland are also noted for their peat bogs, which furnish a kind of fuel.

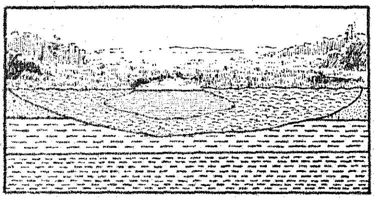


FIG. 101.
Diagram showing a peat bog in section. To illustrate the extinction of lakes by growth of sphagnum.

In the bogs the vegetation does not decay, as it does where it falls on the ground in the forest; for, as it commences to decompose, substances are produced which give antiseptic properties to the water. So, for hundreds of years, bogs may preserve the prints of the beaver teeth upon the tree trunks which they have cut; and the bones of ani-

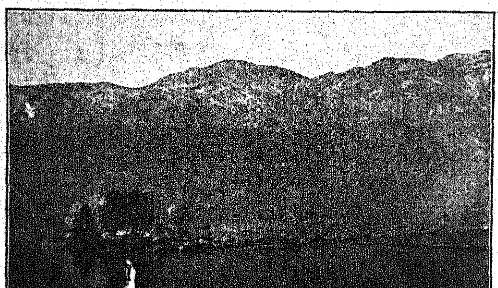


FIG. 102.
Deposits of carbonate of lime precipitated from solution in Lake Mono, in the Sierra Nevada.

mals may resist decay, and lie in this muck well preserved.

Chemical Deposits. — In the Far West, and many other arid lands, lakes without outlets have become salt through constant evaporation. In time this action may go so far that some of the salts are of necessity deposited (Fig. 102). By this means layers of common salt, gypsum, etc., may accumulate; and in desert beds, these are frequently found marking the site of recently dried lakes. They may even now be seen forming in some salt lakes.

By a climatic change to aridity, preventing overflow, even our Great Lakes would become salt, and in their beds, chemical precipitates might eventually be made. In the Great Basin of the West there were once great lakes which were fresh and had outlets, where now, by a change in climate, only salt beds, alkali flats, or salt lakes are left in the lowest parts of the old lake basins. The Great Salt Lake is the largest of these remnants.

The water of this great inland lake is so salt that it furnishes a source of this substance. Led into shallow pans, it is exposed to the dry air of the desert and evaporated so that a layer of salt is precipitated. Here man is doing artificially what nature has done elsewhere when entire lakes have been so evaporated, and beds of salt accumulated in the former lake bottom. We are at present drawing upon these stores in the earth for much of the salt which we use.

THE DESTRUCTION OF LAKES

SEDIMENT DEPOSITS.	Lakes filter the water of the streams. Deltas built. Sediment accumulated over the bottom. Lake waves add to this supply.
ANIMAL DEPOSITS.	Every animal that dies in the lake adds something to the deposits. Sometimes animals are abundant enough to cause accumulations of marl and of infusorial earth (see p. 91).
PLANT DEPOSITS.	Plants do the same. They are usually the final agents of lake filling. Reeds, moss, etc., are important. Peat bogs are formed, and the lake finally becomes a swamp.
CHEMICAL DEPOSITS.	In lakes without outlets the mineral substances brought in solution by the river are sometimes precipitated, when by evaporation the water becomes saturated. In this way beds of carbonate of lime, gypsum, and salt are deposited.

CHAPTER XI

GLACIERS

General Statement. — Among the mountains, and in the high latitudes of the earth, snow falls in the winter and accumulates on the ground. In most places this disappears with the coming of spring; but in the polar regions, and on many high mountains, the winter's snowfall does not melt away in the summer. Each year a little more is added to the mass, until finally it must move from its place of accumulation. In the mountains it does this by slowly flowing down the valleys as *valley glaciers;* but from such immense snow fields as that of the great Antarctic continent, or the one in Greenland, vast sheets of ice spread out in all directions from the centre of accumulation, forming great *continental glaciers.*

In recent geological times, such an ice sheet moved down from the Labrador peninsula, over northeastern America, as far south as the latitude of New York (p. 475). Since its effects upon our country were so marked, the subject of glaciers becomes one of more

importance than if we had merely to consider the rare glaciers of the present.

Valley or Alpine Glaciers. — *Location.* These are often called alpine because they have been carefully studied in the Alps, where they are numerous and

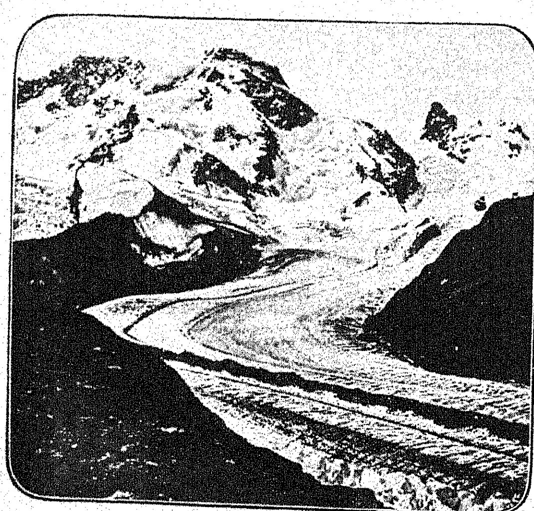


FIG. 103.
An Alpine glacier, showing snow field, ice stream, and medial moraine.

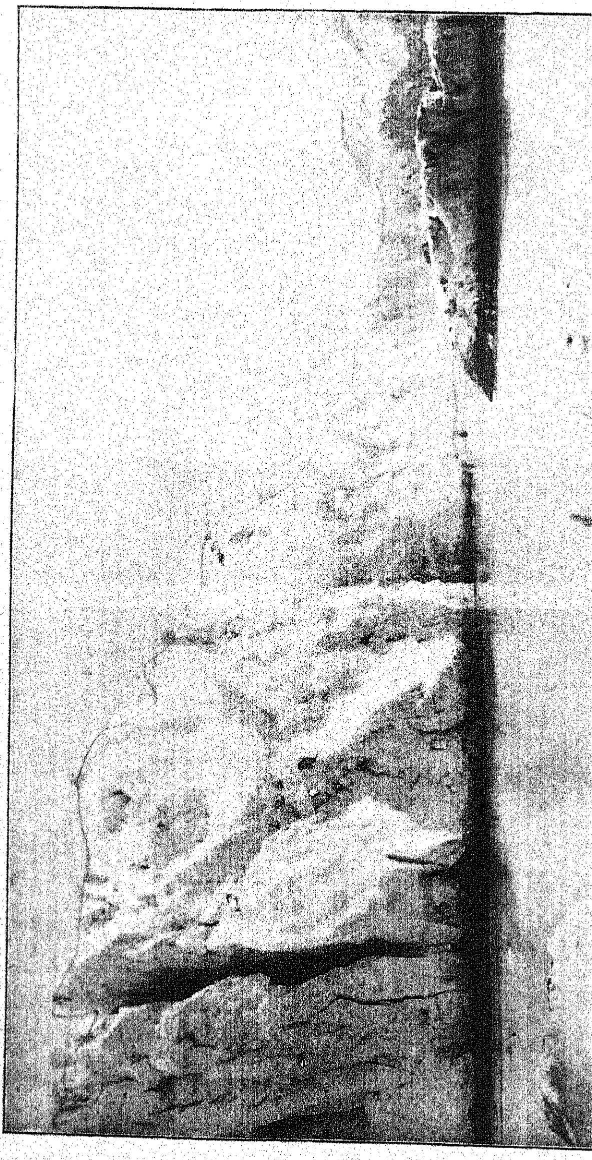
well developed. In this range of mountains, there are no less than two thousand different glaciers (Fig. 103). As geographical knowledge has been obtained from remote parts of the world, valley glaciers have been found in many of the mountains of the earth. On the North American continent, small valley glaciers exist

in the Sierra and in various parts of the northwest. When western Canada is reached, they become more numerous, and from here all the way up to Alaska, are very common among the mountains. In many places, as for instance at the famous Muir glacier, they reach the sea (Plate 9).

The condition necessary for the formation of a glacier, is an excess of snowfall over melting; and so in higher latitudes, where the winter snowfall is great, and the summer temperature low, glaciers may form even at a comparatively slight elevation. Even in the same latitude it may happen that glaciers exist in some mountains, where the precipitation is heavy, while other mountains of equal height, situated in a drier region, are without them. This is one of the reasons for their absence in the higher valleys of the middle Rockies.

Characteristics of Valley Glaciers. The valley glacier is commonly said to consist of three parts: (1) the *snow field* (Figs. 103, 104, and 108), which is the place of accumulation; (2) the *névé*, where the change of the snow to granular ice, and the movement down the slope have begun; and (3) the *ice stream* (Figs. 103 and 108), or glacier proper, which is a mass of ice compacted from the snow.

The glacier may be likened to a stream; for the snow field is the vast supply ground, comparable to the drainage area of a river, and the glacier is a



slowly moving ice stream in a valley. All over the mountain tops the snow falls, and wherever the slope is moderate enough to allow it to stand, it accumulates to great depths; but where the mountain is precipitous, the snow slides down into the valley, often in the

FIG. 104.

A snow field in the high Alps.

form of great avalanches. Some of the snow is also blown by the wind from the mountain tops into the valleys.

As the mass of snow in the valley deepens, and becomes transformed to ice, it commences to flow[1]

[1] Ice is commonly said to be viscous. Some object to this term and propose "plastic." Owing to the confusion which exists, it seems well not to use either term, but to say that it behaves like a viscous body, of which wax is a good example. Moreover, there seems to be little reason for doubting that ice really is viscous.

PLATE 9.

Front of the Muir glacier, Alaska, where it enters the sea.

something like wax or pitch; and as it continues to move, seeks the lowest ground, just as water does. So by this means an ice stream is formed, which continues to flow either until it meets the sea, or more commonly, extends far enough below the *snow-line*[1]

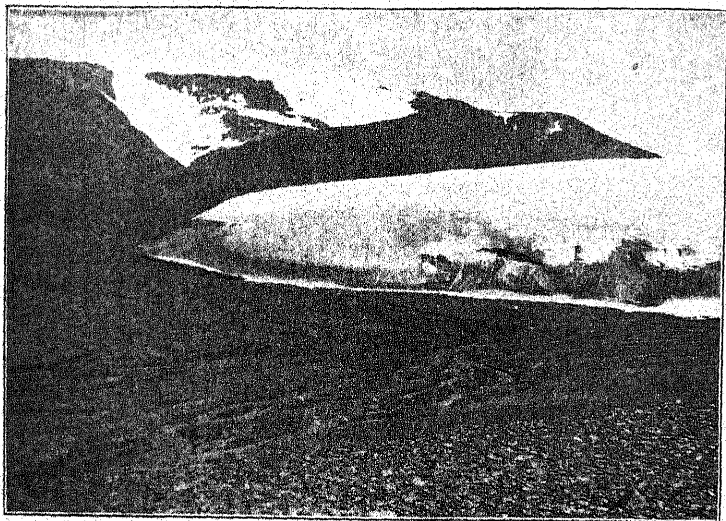


Fig. 105.

Terminus of the Robertson glacier, North Greenland, showing stream flowing from ice front.

(Fig. 103) to reach the point where the warmth of the sun and air can melt it. From this place, which is the front of the glacier, there flows a stream which is furnished with water by the melting ice (Fig. 105 and

[1] The snow-line is the line of permanent snow, as for instance on a mountain top, where it always stands.

PLATE 10.

Map of Swiss glacier with streams issuing from terminus.

Plate 10). In this is transported some of the rock material which the glacier was carrying.

Valley glaciers differ very much in their features, particularly in their width, depth, and length. There is much difference according to the supply of snow, the slope of the valley, and also its width. The glaciers of

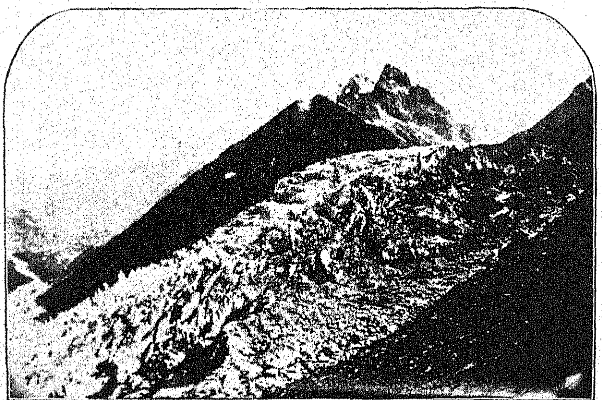


FIG. 106.

An ice-fall in one of the Swiss glaciers.

the Alps (Plate 10) are often five miles long, while the Aletsch is ten miles in length, over a mile wide, and more than one thousand feet in depth. Many of the Alaskan glaciers are much larger and grander than those of the Alps.

As the ice moves over its rock bed, it sometimes encounters a steep descent, and then the glacier surface becomes broken and irregular, forming an *ice-fall*

(Fig. 106) which in character and origin resembles the waterfall or rapid of a river. Elsewhere in the glacier the ice may be rent asunder, making great cracks, or *crevasses*, which reach far down into the ice, possibly even to the bottom. Again, the melting of the surface

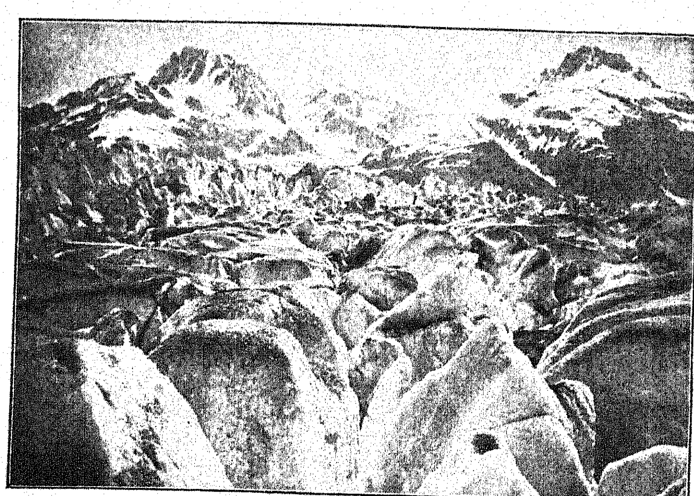


FIG. 107.
Rough surface of Muir glacier, Alaska.

of the ice stream often roughens it with pinnacles and pyramids, so that in some places the surface cannot even be crossed (Fig. 107). In other parts of the glacier, the surface is much smoother and more easily travelled.

Moraines. Moving down the valley, the glacier, like the river, is bounded by banks often of steep ascent.

From these rock walls, disintegrated material frequently drops upon the back of the glacier, either as single pieces or in the form of great avalanches. So the sides of the valley glaciers are littered with rock debris, which is slowly moving down with the ice. It

FIG. 108.

A Swiss glacier, showing snow field, ice stream, medial, lateral, and terminal moraines.

is a moving talus, and is called the *lateral moraine* (Fig. 108).

Where two glaciers unite, two of these moraines may meet in the centre of the resulting glacier, forming a *medial moraine* (Figs. 103, 108, and 109). Some of the rock fragments of the surface, fall to the bottom of the ice through the crevasses, and these join

with the debris that the glacier is able to rasp from its bed. This loose rock material beneath the ice is called the *ground moraine* (Fig. 109).

All the rock material is gradually carried toward the front of the ice, where melting cuts off further progress. The stream that flows out from the *ice cave* (Fig. 110) at the margin of the glacier, is able to bear away some of the finer fragments; but much

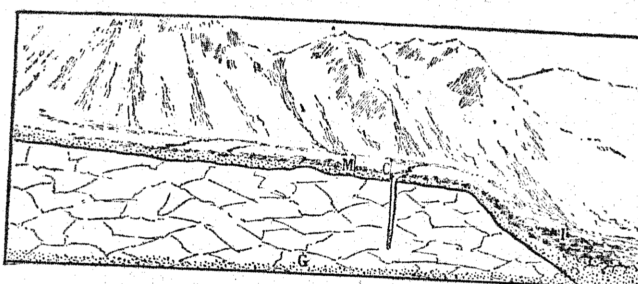


FIG. 109.
Diagram to illustrate position of ground moraine *G*. Also shows medial moraine *M*, crevasse *C*, and terminal moraine *I*

of the burden accumulates at the front end, forming a fourth moraine, the *frontal* or *terminal moraine* (Figs. 108, 109, and 111).

These various moraines are all made of irregularly arranged rock fragments, of various kinds and sizes, transported from the several parts of the glacier valley. Not only is there a complexity of material in the moraine, but the *form* is also irregular and confused. The hills and hillocks are hummocky in the extreme.

Rate of Movement. The rate of movement of the glacier is always very slow, and varies with the season, the slope of bed, the part of the glacier, and other conditions. It moves more rapidly in summer than in winter, and in the centre than on the margins.

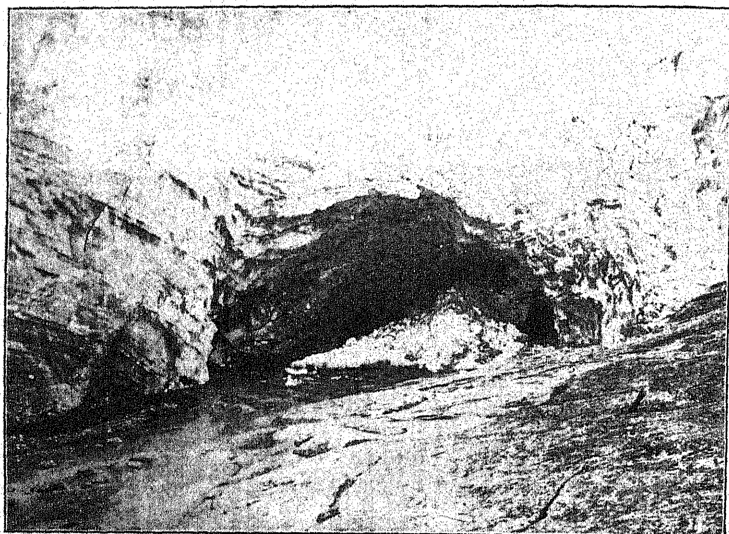


FIG. 110.

Stream issuing from an ice cave in the Bowdoin glacier, Greenland.

Usually the ice moves only one or two feet per day, though the Muir glacier travels at the rate of about seven feet a day. So slow is the movement, that careful measurements must usually be made in order to detect it; but the ice stream flows on with constant

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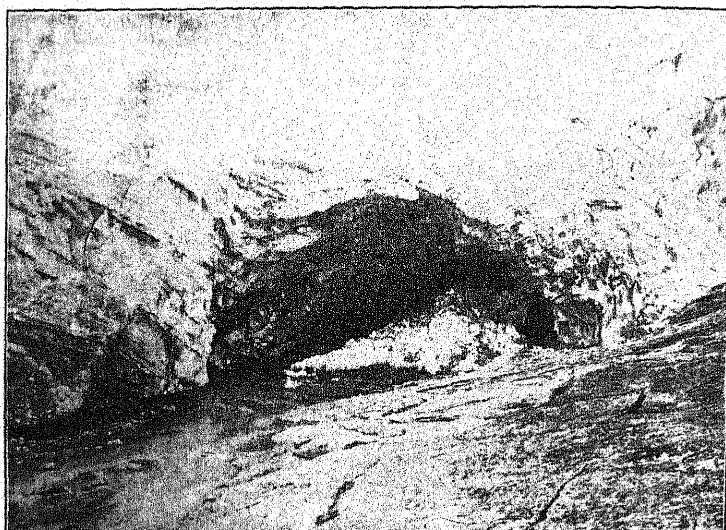

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Usually the ice moves only one or two feet per day, though the Muir glacier travels at the rate of about seven feet a day. So slow is the movement, that careful measurements must usually be made in order to detect it; but the ice stream flows on with constant

and irresistible force, until its enemy, the sun, transforms it to water, when it courses rapidly down the mountain valleys in torrential streams.

Work of the Glacier. The ice sheet is a great agent of transportation. It differs from the river in this respect,—that being a solid, it will bear along large and small fragments side by side, even though its

FIG. 111.
End of a Swiss glacier, showing terminal moraine.

rate of motion is very slow. Hence the deposits made by the glacier bear no relation to its velocity, being compounded of fragments of all sizes, thrown together where the ice left them.

Another difference between rivers and glaciers is found in the work of erosion which they do. The river bears along sediment, buoying it up and lessening its weight, but hurling it against the river bed;

the glacier, hundreds or perhaps thousands of feet in depth, *drags* the materials along. On account of the weight of the ice above, it acts like a sandpaper, pressing down with great force.

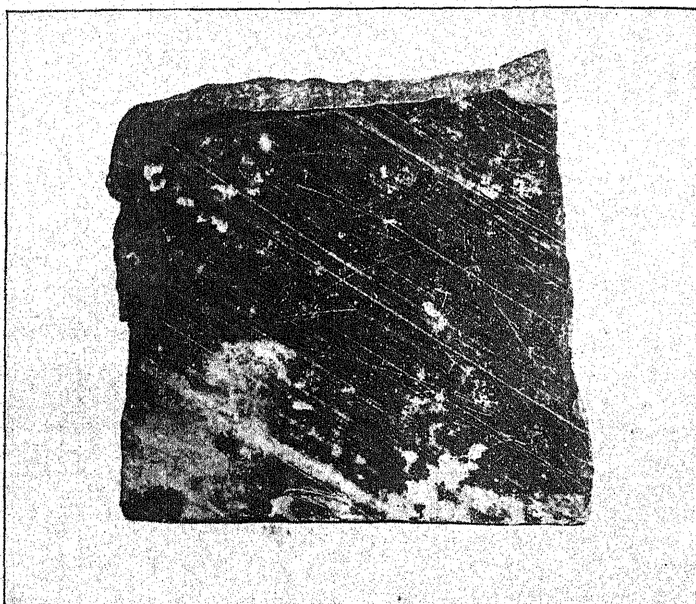


FIG. 112.

Rock over which a glacier has moved, forming glacial striæ.

So the rock of the glacier bed may be carved and polished, while the fragments themselves are thoroughly ground. Rocks over which ice has moved, (Figs. 112 and 268), and pebbles that have thus been dragged along (Fig. 113), are often striated by this

action, thus showing the great work of scouring that is being done. As one rock is thus ground against another, a fine clay or *rock flour* is worn off, and to this mixture of clay and pebbles, is given the name of *bowlder clay* or *till*[1] (Fig. 114).

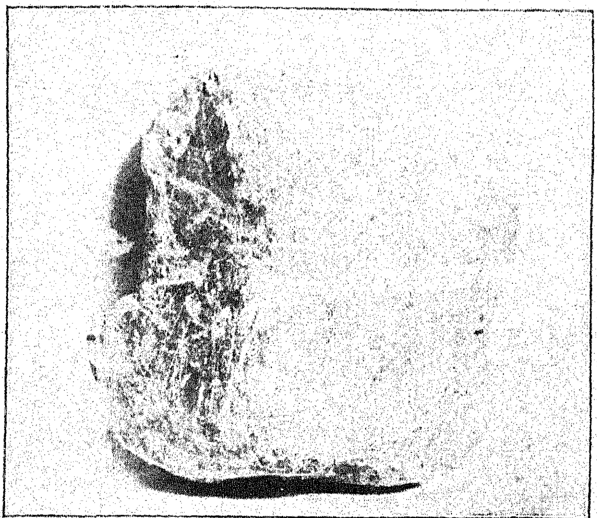


Fig. 113.

A pebble that has been carried by ice and smoothed and scratched.

There is a difference of opinion among geologists as to how much a glacier wears against its bed, some holding that little is accomplished, others believing that

[1] Many of the names and facts set forth in this section apply to other glaciers besides the valley. Hence some of the illustrations are from deposits left by the extinct American continental glacier (p. 475).

P

valleys are deepened and basins of rock carved out. Since we cannot observe the work being done beneath the ice, we cannot be certain upon this point, though a mass of evidence, gathered in regions once occupied by glaciers, indicates that the latter view is the more nearly correct.

In whatever way the materials are obtained and

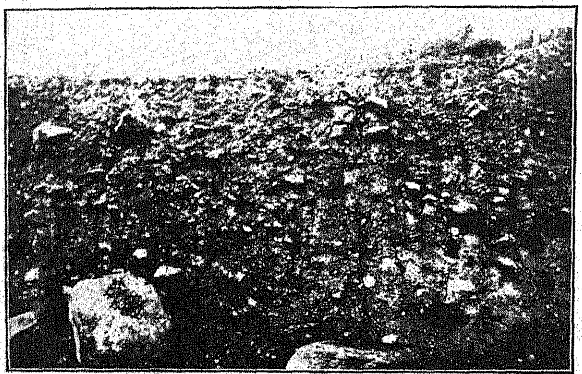


FIG. 114.

Photograph of a bed of bowlder clay in Pennsylvania.

transported, if the ice departs, the various moraines are left behind as proofs of former ice presence. In the place once occupied by a valley glacier, there would therefore remain a general sheet of till or bowlder clay, representing the ground moraine; and thicker accumulations would be found where the lateral, medial, and terminal moraines existed.

Besides these *unstratified* deposits, the water which flows from the margin of the ice, frequently carries more sediment than it can move down the valley; and some of this is then built up in the stream valley, as assorted or *stratified* river deposits of sand, gravel, or clay (Fig. 115). Along the margin of any glacier,

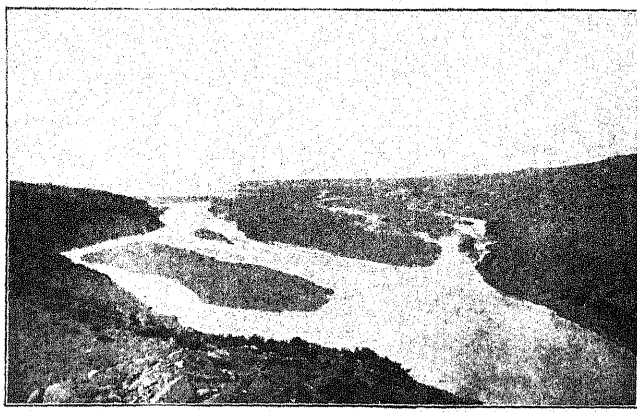


FIG. 115.

A stream from the end of the Malaspina glacier, Alaska, depositing gravel in its bed.

such accumulations are made; and they, like the beds directly deposited from the glacier, may be seen in places once occupied by ice.

Former Extent of Valley Glaciers. Below the ends of all valley glaciers, and in many mountain valleys now free from them, there is abundant evidence that in recent times these ice sheets were more numerous

and extensive than now (Fig. 116). From this we may fairly infer that there has been some change in climate.

FIG. 116.

A map of a part of the Sierra of California, showing former extent of valley glaciers. Existing glaciers marked black.

The evidence of this is (1) the presence of smoothed and grooved rocks, (2) bowlders whose original home was higher up in the mountains, and (3) moraines (medial, lateral, ground, and terminal), now resting in the valley bottom, where they were left when the ice melted. Where hillocks of morainal debris are stretched across the course of streams, lakes are present (Fig. 117), as they are also in basins of rock, which the ice appears to have gouged out. This evidence is in harmony with that which has led us to believe that North America and Europe were recently the scene of extensive ice action, when a

glacier larger than that of Greenland covered these lands.

Continental Glaciers. — At present there exist on the earth two great continental glaciers, one sur-

FIG. 117.

Terminal moraine and enclosed lakes in a Rocky Mountain valley, in which no glaciers now exist.

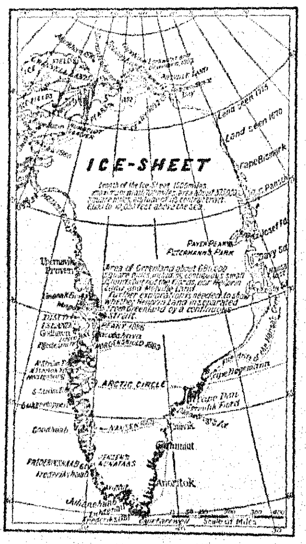


FIG. 118.

Map of Greenland. Shaded part shows land, white part, ice cap and glaciers.

rounding the South Pole, and covering the Antarctic continent, the other spreading over nearly all of the great Greenland island (Fig. 118). The area of the Greenland ice sheet is fully 500,000 square miles, and that of the Antarctic is believed to be much greater.

The interior of these immense ice sheets is a vast snow field, that of Greenland rising 5000 to 10,000 feet above the sea, while the depth of the ice is certainly several thousand feet. Whatever may be the condition of Greenland beneath

the ice covering, the interior is completely hidden by an ice cap (Fig. 119). The rock of this land appears only at the margin, either at the very seashore or just inland from this, where mountains project above the ice sheet.

Along the margin of Greenland, the glacier divides

Fig. 119.

The Bowdoin glacier, Greenland. A tongue of ice extending down a valley from the ice cap seen in the background.

into tongues, sometimes surrounding mountain peaks, which are known to the Greenlanders as *nunataks*. In many places the ice enters the sea with solid front; but often it merely passes down the valleys in the form of tongues of ice, which have many characteristics of other valley glaciers. Excepting at the margins of these

sheets of ice, there are no moraines upon the surface, for no rocks rise above it to furnish debris. But beneath the ice there is probably a ground moraine (Fig. 120), and we are certain that terminal moraines are being constructed at the margin.

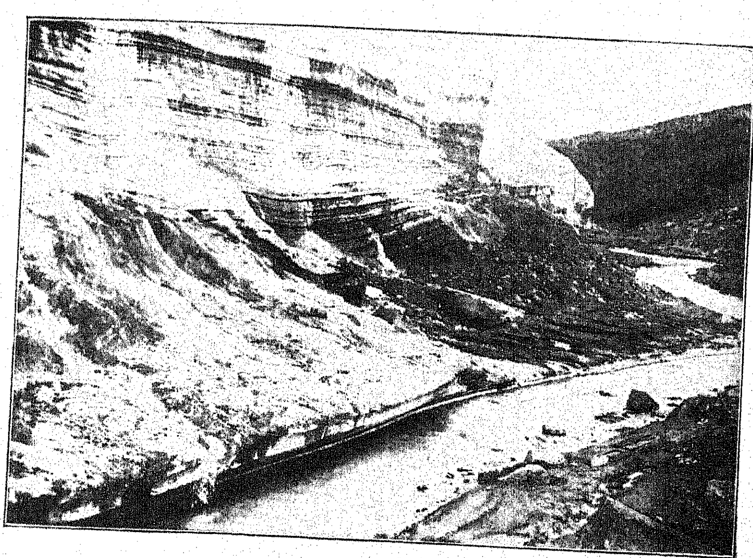


FIG. 120.
The margin of the Bowdoin glacier, showing ground moraine in the base of the ice cliff.

The continental glacier also differs from the smaller valley glaciers in not being confined to valleys, but in moving over the country, in a measure regardless of the topography. There is a resemblance between the two classes of glaciers in the slow movement and the

irresistible power of the ice. We may fairly believe that, as the great continental glacier slowly passes over the land, it grinds its bed, just as the valley glaciers do. Probably it is wearing down the hills and deepening the valleys, and perhaps even gouging out rock basins. In the great sheets of ice which now exist, we no doubt have an illustration of the conditions from which the northeastern part of North America, and the northwestern part of Europe have recently escaped (p. 475).

Piedmont Glaciers.—Within a few years a new type of glacier has been described from Alaska. This is the Malaspina glacier, which covers the plain between the sea and the base of Mount Saint Elias, from which the glacier is fed by a number of valley glaciers, reaching from the great snow fields of the lofty mountains.

There are many interesting features connected[1] with this glacier, one of the most notable of which is, that the motion near the margin has so decreased that a forest is able to grow upon the surface of the glacier (Fig. 121). The soil in which it grows, is the moraine that has accumulated to a considerable depth on the margin of the nearly stagnant glacier. The cause for the almost entire absence of motion is the fact that

[1] It is impossible to give more space to their consideration. A description of them may be found in articles by Prof. I. C. Russell in Vol. III., pp. 53–203, of the National Geographic Magazine and the Thirteenth Annual Report of the U. S Geological Survey, pp. 1–91.

the ice is moving over a plain, and the supply from behind is not sufficient to push it rapidly forward.

Icebergs. — Where glaciers enter the sea, the tide cuts off fragments which float away as bergs; or as the glacier moves out into deep water, it is buoyed up and large pieces are thus cracked off. These icebergs (Fig. 122), which come abundantly from the great Greenland and Antarctic ice sheets, are often of immense size, being veritable islands of ice, which float hundreds and even thousands of miles before melting.

Fig. 121.
A view in the forest on Malaspina glacier, Alaska.

Some have been measured whose height above the water was five hundred feet, and whose length and width must be estimated in thousands of feet, while some are reputed as more than a mile in diameter. As the proportion of ice below the water is 8.7 to 1

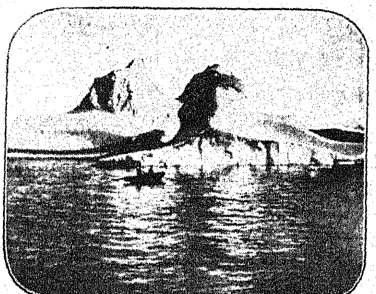


Fig. 122.
An iceberg in Baffin's Bay.

above, some of these large bergs must measure nearly a mile from the top to the submerged bottom. They carry with them a portion of the rock fragments of the glacier, and as they melt, these are strewn over the bed of the sea, sometimes at a great distance from their source.

It is occasionally said that berg deposits have built shoals in the sea; but undoubtedly the action of icebergs in this respect has been greatly exaggerated. They are probably of much more importance in modifying climate than in making deposits in the ocean.

WORK OF GLACIERS.

CAUSE.	Formed where snowfall exceeds melting; hence in higher latitudes even near sea-level, and among lofty mountains of lower latitudes, at higher elevations.
KIND.	*The valley glaciers:* formed in higher land; descending in valleys. *The Continental glaciers:* of wide extent, submerging the land. Have valley glaciers at terminus. *The Piedmont glaciers:* nearly stagnant ice sheets on a plain, supplied by valley glaciers of mountain.
CHARACTERISTICS.	A snow field as the supply area. This compacts into ice and then slowly flows away, either reaching the sea and floating away in the form of icebergs, or melting. Has moraines, lateral, medial, terminal, and ground. If on the land has a stream at its end. Surface roughened by cracks caused by movement and by irregular melting.

WORK OF GLACIERS (*continued*)

EROSION.	They scour the rocks over which they pass and grind both these and the materials carried, forming clay. Rocks striated and polished. Hills and valleys worn as ice passes over them.
TRANSPORTATION.	Carries rock fragments of large and small size side by side in the moraines of various kinds.
DEPOSITION.	Moraines of hummocky outline, and unassorted clay and bowlders left by the ice. Ice-born streams deposit assorted beds of stratified sand and gravel. Lakes often formed by dams of these accumulations. In the sea, icebergs aid in the distribution of the rock materials; and at the margin of the ice which enters the sea, deposits are made directly.

CHAPTER XII

AGENTS AT WORK IN THE OCEAN

Agents at Work. — The ocean, like the land, is a seat of geological change; but while the principal action on land is that of *destruction*, in the sea the main work is *deposition* and *construction*. Yet along the coast line there is constant erosion. This is of great importance. The oceanic agents that are engaged in the double task of tearing down and building up, are waves, tides, ocean currents, animals and plants. The work of construction in which these are constantly engaged, is greatly aided by the material which rivers are bearing into the sea.

Chemical Work. — Dissolved in the sea water are vast quantities of rock material, which have been taken from the land by means already described. In some places these are being precipitated from solution in the form of chemical deposits; but so far as we are able to tell from our present knowledge of the sea bottom, this action is comparatively of little moment. By far the

most important service performed by this load of dissolved substances, is the furnishing of materials which many animals and plants need for their existence. Thousands of tons of carbonate of lime and other substances, are being daily extracted from the water by animals, and built into their skeletons or shells. This process is of no little consequence in the formation of rock deposits in the ocean (p. 89).

A large percentage of this dissolved load is brought by streams, but the very presence of sea water in contact with the rock, furnishes another source. Just as the water of the land is able to dissolve and modify the minerals of the rocks, so the ocean water works constant destruction along the coast line. The rate of change caused in this respect by sea water is greater than that of rivers, because sea water is more impure, and hence a more powerful agent of solution. On some rocks, such as limestone, sea water is producing marked changes (Fig. 123). One may often see its effects upon rocky coasts dashed by the ocean spray.

Wave Action. — *Nature of the Wave.* In the sea the friction of the wind on the surface of the water produces waves, whose height in the open ocean is often one or two score of feet. Even a slight breeze ripples the surface, and the billows which are raised by the storm winds, will extend for great distances

from the place where they were formed. So the surface of the sea is constantly disturbed, and even in calm weather the water heaves with the passage of swells which have originated far away.

In the open ocean these waves do almost no geological work. The surface rises and falls, and any floating

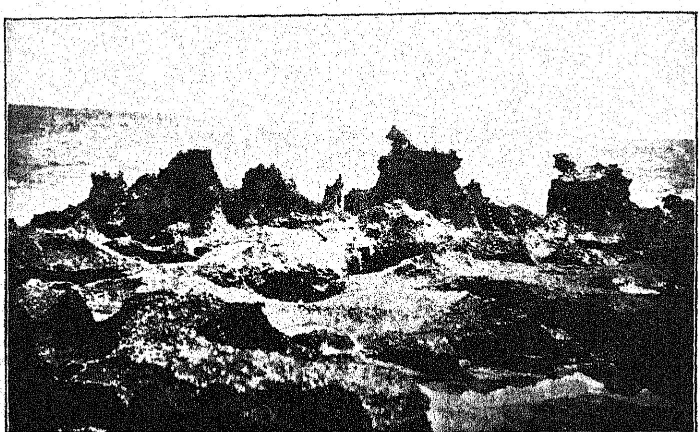


FIG. 123.

The limestone of the Bermuda coast, roughened by solvent action of the sea water.

object merely moves up and down, while the wave passes on. There is a slight forward and backward motion in the wave, because the water particles do not rise and fall vertically, but pass through an elliptical path. There are, therefore, two important movements in the wave, one of the water particles

(an elliptical rise and fall), and the other the wave passage itself, which is horizontal, and merely a transmission of motion, not a bodily transfer of the water. When the wind is blowing there is a third movement, a slow drift or current of the surface water carried in the direction of the wind. Therefore, a floating object will move forward a little, though never nearly so fast as the wave form.

Reaching the shallower water of the coast, the wave begins to change its habit (Fig. 124). It is a disturb-

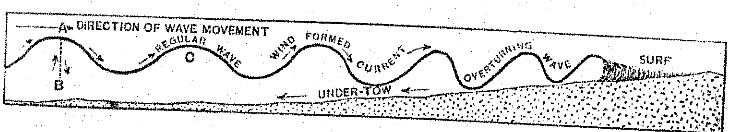


FIG. 124.

Diagram to show approach of a wave upon a beach.

ance of the water extending to a depth of several feet or yards, and in great waves several score of feet. In the open sea this can proceed with no other interference than that of the water itself, but on the shallowing coast the true wave movement is partly checked. The wave then travels faster at the top than at the bottom; it overtopples and rushes upon the coast as a breaker, hurling tons of water against the shore with terrific force (Fig. 125). Oftentimes the onset of the wave is vigorous enough to move bowlders several tons in weight. At the same

time there is an outward movement of the water at the bottom, which is known as the *undertow*.

Wave Attack. One of the ways in which the wave does work, is to batter at the dense rocks of the coast. In these there are usually crevices filled with air or water; and as the wave beats against the rocks, it

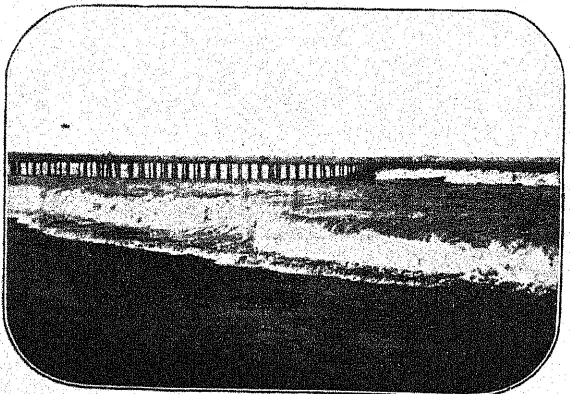


FIG. 125.

Surf at Long Branch.

produces a pressure upon these which exerts sufficient force to rend off fragments of great and small size.

With these rock fragments, added to others furnished by weathering, by streams, or any other cause, the waves batter at the coast and wear it away. It is by means of these tools that the greatest work

of the waves is done. If they are beating against a cliff, they gradually eat it away and cause it to retreat toward the land; if they break upon the beach, surging backward and forward, they grind the rock fragments to sand and clay. The coast line is a great mill, whose never-resting engine is the wind wave.

Aid of Currents. Soon this work of the waves would be self-destructive if there were not another action in coöperation. Just as those rivers furnished with more sediment than they can carry, are prevented from cutting their channels deeper, so waves that cannot dispose of the materials which they obtain, are hindered from wearing back the land. On many parts of the coast south of New York this condition prevails, and the waves are building bars off the real coast, instead of eating back into the land (Plate 11).

Currents of various kinds, some of wind origin and others resulting from tidal action, are constantly removing the finer fragments which the waves have prepared. The work of tidal currents is considered in its proper place (p. 231), and we have now merely to examine that of the undertow and the wind currents, which coöperate with the tidal movement in the transportation of sediment and its deposition over the ocean bottom.

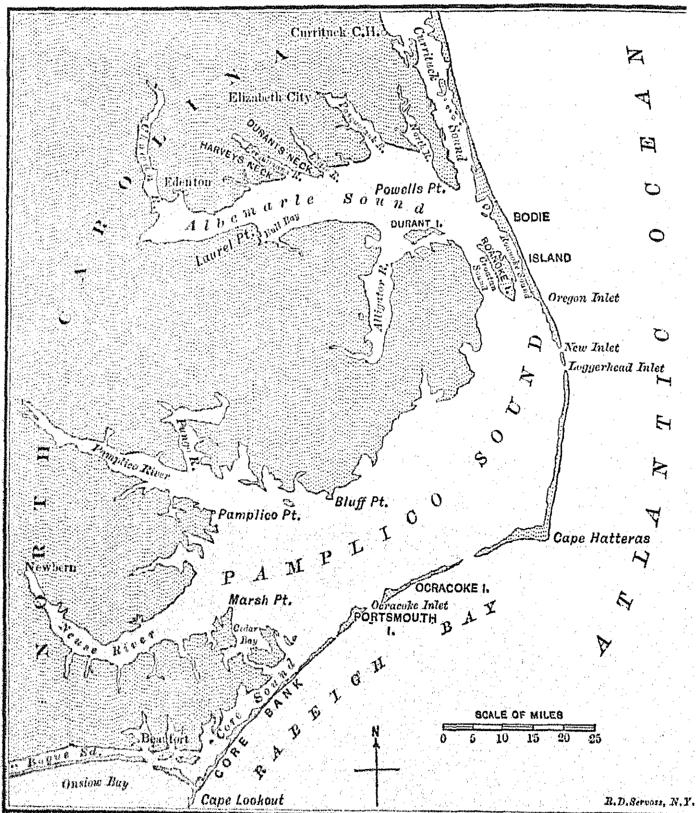


PLATE 11.

Map showing the bars built off the Carolina coast.

By the undertow,[1] fragments are dragged out to sea along the bottom. Worn upon the beaches, the finer fragments in part pass outward, lodging finally on the sea bottom at a distance from the coast, where the force of the undertow current has so diminished that further transportation is impossible.

The blowing of the wind starts a slowly moving surface current, in which fragments may also be carried. Also, as waves strike the coast, reaching it diagonally, a shore current is produced in connection with the change from the wave proper to the breaker, which is a bodily forward movement of the water. In this way, fragments, often of considerable size, are driven along the shore (Fig. 126). So the waves have allies (including the tides), which serve to clear away the materials that they have prepared for removal, and thus leave the shore open to their further attack.

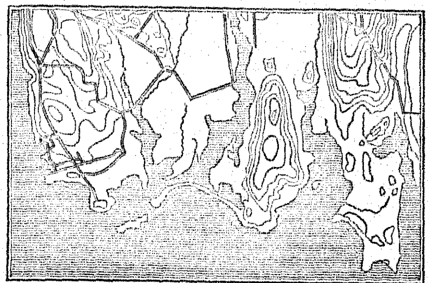
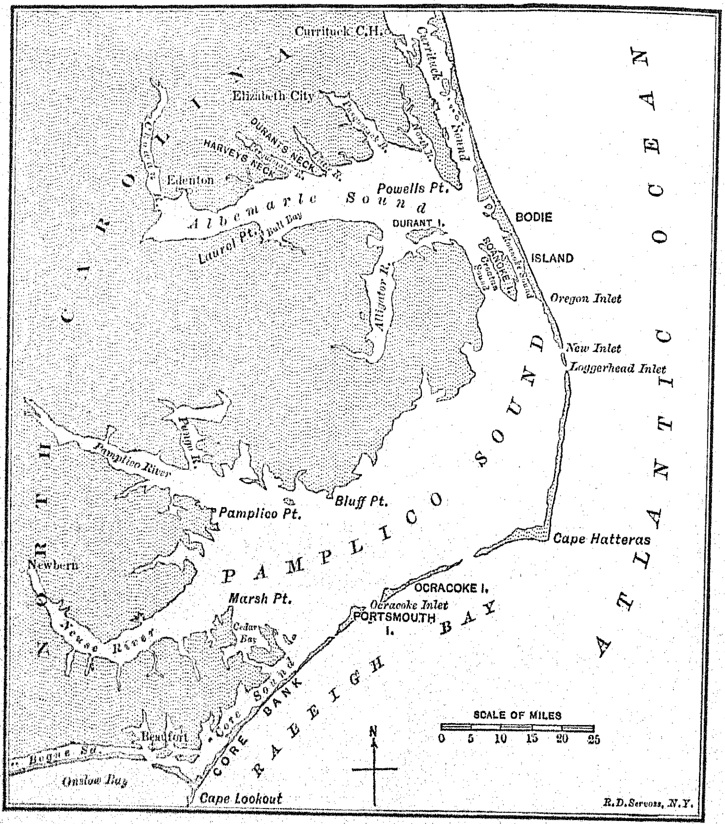


FIG. 126.
A part of the coast of New England, showing bars built by waves and shore currents moving in the direction of the arrows.

[1] The action of the undertow is often illustrated disastrously when bathers are caught by it, dragged to the bottom and carried out, being held under until life is extinct.



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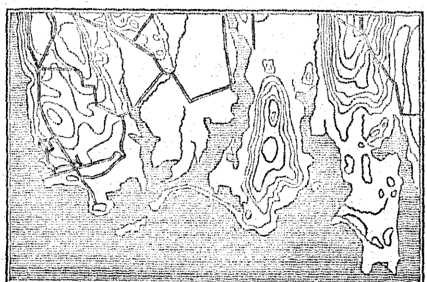

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Results of Wave Action. By chemical action, direct wave attack, and the hurling of rock fragments against the coast, the shore is driven back. The line of chief activity is at the water level, and here the waves and water saw their way into the rock. By this

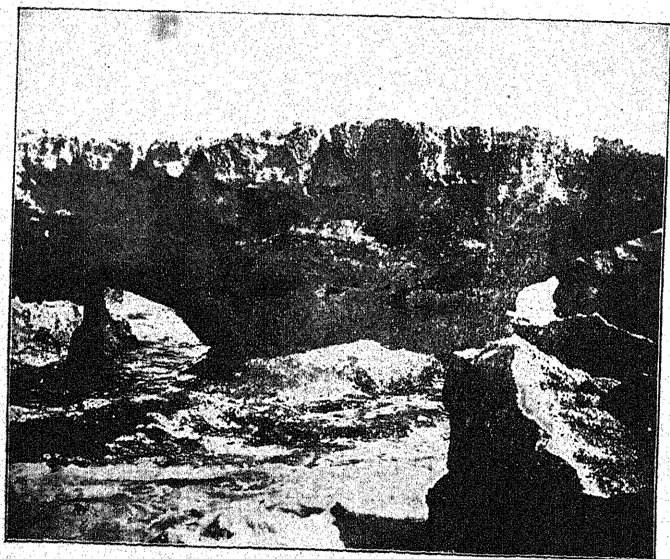

FIG. 127.
Limestone cliffs in the Bermuda Islands, undercut by waves.

action hard rocks are sometimes cut into the form of cliffs, undercut at the water line (Fig. 127). In other cases the waves work locally, with sufficient energy to carve out a *sea cave* (Fig. 128). Soon the cliff above becomes unstable, and a part must fall. Hence the cliff

maintains a nearly vertical position (Fig. 129). But weathering, also operates to wear it back, and therefore it may not be absolutely vertical. If the coast rock is soft, the wave-formed cliff will be a sloping one.

The methods of wave action vary widely with the conditions. In case the products of this coast mill can be removed, cliffs are cut and sometimes beaches built at their base, representing the accumulated materials which have not yet been carried away (Fig. 129). These sea cliffs may be very irregular, for the waves will cut into some rocks more readily than others; and thus headlands will be made to jut beyond little indentations (Fig. 130), which mark the site of the more easily destructible rocks.

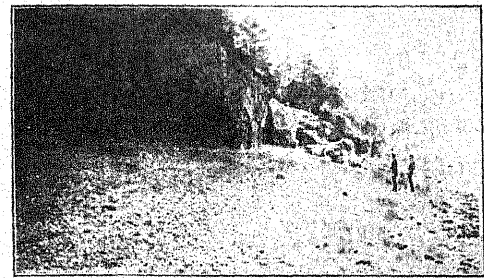

Fig. 128.
Sea cave in cliff at Mt. Desert Island, Maine.

It is sometimes stated that harbors, estuaries, and bays, even those as large as the Chesapeake, have been cut out of the land by the action of the ocean; but this is an error. Such large irregularities have been caused by a sinking of the land, which has allowed the sea to enter river valleys and transform them

into bays, while the hills jut into the seas as headlands.

Those headlands which are exposed to ocean attack, are being worn back at rates varying chiefly with the

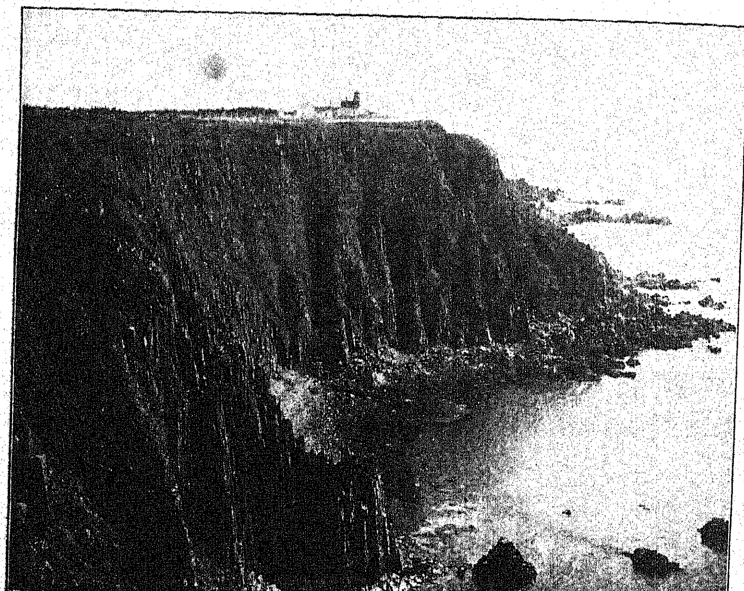

FIG. 129.
Sea cliff at Grand Menan, with a small beach at the base.

force of the waves and the nature of the rock. The materials ground off go partly out to sea and partly along the coast, being moved in the latter direction by the wind-formed and tidal currents. Coming to the mouth of a bay, or other indentation, these rock fragments are

driven in as far as they can be moved; but since the force of the waves decreases in these narrow, protected re-entrants, a place is soon reached where all but the finer particles must be deposited. So a *bar* is commenced, and this may later grow into a beach, which may completely extend across the mouth of the bay (Fig. 131). This beach then becomes the mill on which the waves, in more leisurely fashion, grind up the fragments that were wrested from the cliffs.

FIG. 130.

Indentation in coast of Cape Ann, cut by waves which have removed a dike rock from the more durable granite walls.

Action of the Tides. — Twice each day, by the combined effect of the attraction of sun and moon, the surface of the ocean rises and falls (Fig. 139). In some places the range between high and low tides is only a foot or two; in others it is ten or twelve feet; and in one or two places it reaches a height as great as forty or fifty feet.

Even in neighboring bays, the tidal range may differ by several inches or a foot; and if these bays are connected by a strait, the difference in the height of the

ocean surface will cause currents to flow backward and forward through this. Thus on many coasts, particularly those that are irregular, the tide, which naturally is merely a rising and falling of the water, becomes a true moving current. These currents may grow powerful enough to destroy land, and they are

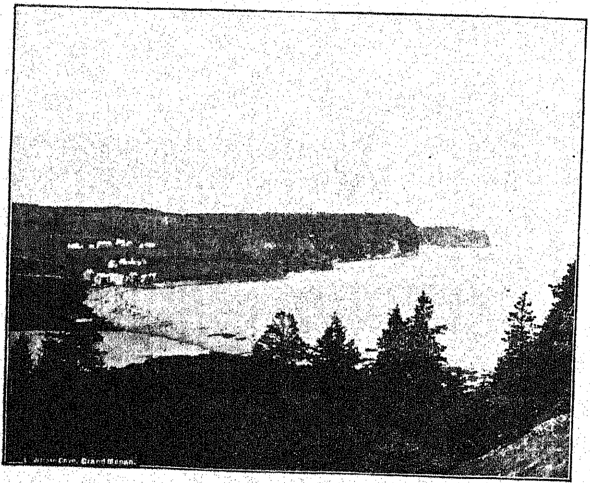

Fig. 131.

Cliffs and beach enclosing a bay at Grand Menan.

always at work transporting sand and clay along the coast, or out to sea.

Therefore one of the most important effects of the tides, is to move sediment about from place to place. They also increase the range of the wave work, because they raise and lower the ocean level. Rocks

which at high tide are covered, at low tide are exposed to the air; and so the zone of wave attack is swung up and down twice each day. Ordinarily this increase in vertical range is not great; but where the tide rises a score or two of feet, it causes a marked influence on the nature of the wave work.

By this means, too, in the winter, where the climate is cold, ice is formed in the crevices of a rock from whose face the tide is falling. This, freezing at low tide, and melting when covered by the water, prys open the crevices and breaks off particles in a manner analogous to frost work in weathering (p. 112). Ice is formed every winter on some coasts; and as the tides rise and fall, or as the waves dash against the shore, these icy masses, in which pebbles and bowlders are often frozen, are ground against the coast, aiding in the work of destruction.

Effect of Organisms. — In the sea the most important work of organisms is the construction of beds of sediment; but along the sea-coast they sometimes aid or interfere with the erosive work. Sea-weed, barnacles and other kinds of plants and animals, cling to the rocky coasts in many places (Fig. 139). These aid erosion by prying off fragments as they grow, just as is done by plants on the land. Some sea-weeds also buoy up pebbles, and allow the waves to more easily drive them on the beach. How-

ever, the main effect of these organisms is to protect the shore which they cover with a veritable mat, against which the energy of the wave attack is expended.

Destruction of the Coast. — The *amount* of change produced by these oceanic agents cannot be stated, because it varies so much from place to place. On the hard, rocky coast of New England, no noticeable change has been made in the 250 years and more since the Pilgrims came over; yet this is exposed to the action of violent ocean waves. The cliffs on eastern Martha's Vineyard, on the other hand, have been worn at a perceptible rate. The Nashaquitsa Cliffs of this coast have been cut back a distance of 220 feet between the years 1846–1886, or at an average rate of five and one-half feet per year. On the coast of England there are many places where the shore line has moved inland at a measurable rate, in some localities as rapidly as a yard per year.

In such places bars and beaches are also growing as the cliffs are worn back, the materials derived from the cliffs being partly built into the beach. The amount of shore modification which has been recorded in various parts of the world, warrants the belief that the coast line is a scene of constant change, and that in the lapse of ages, wave attack and tidal action have materially altered our sea-coasts.

Ocean Currents. — Aside from the smaller currents which move in the ocean, particularly near the shore where winds and tides cause them, there are larger movements of the sea known as ocean currents. These are slowly moving eddies, which appear to be caused mainly by steadily blowing winds which drive the water before them.

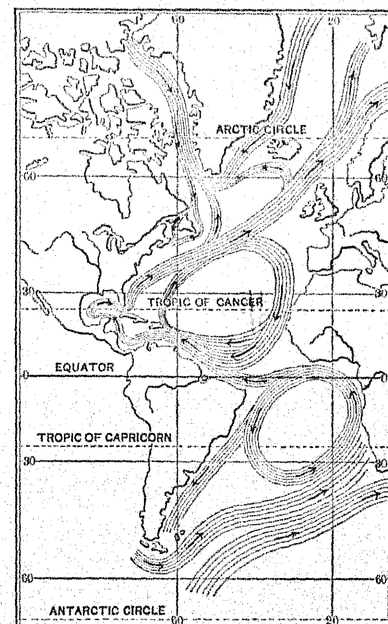

FIG. 132.
Diagram of ocean currents in the Atlantic.

In the Atlantic two sets of winds blow from opposite quarters (the northeast and southeast), toward the equator, causing the surface water to slowly drift before them. This forms a moderate ocean drift or current at the equator, which extends toward the west (Fig. 132). Then, dividing on the coast of South America, one part moves into the South Atlantic, while a second, and larger portion, enters the North Atlantic. The latter, passing along the eastern coast of the United States, bathes it in water which

was warmed in the tropical regions. It then crosses the Atlantic, a part extending into the Arctic Ocean, between Iceland and the European coast, the remainder returning southward along the shores of Europe, where it again enters the whirl. From the cold polar region there are return currents of frigid waters; but these are less distinct than the warm equatorial currents.

These great movements of the water, which are found in every ocean, transport quantities of heat or cold, so that they serve to modify in marked degree, the climates of the ocean and the coasts. For instance, the Bermudas, and even the British Islands, have their temperature raised by the warm Gulf Stream, while a cold Labrador current chills the coasts of Nova Scotia and northern New England, which lie in the same latitude as central Europe. This current is one of the means of transportation of Arctic ice into temperate latitudes.

Since to a great extent the development of the animals of sea and land is influenced by temperature, these movements of the ocean water are of much importance to them. Any change in the course of the flow will produce very decided effects upon life. For instance, if the Gulf Stream did not bathe the European lands, parts of northern Europe would be rendered uninhabitable.

There is no reason for believing that the ocean currents

are active, either in eroding the shores, or in directly building up deposits; the motion is too slow for this. Indirectly, however, they do much work toward the formation of deposits in the ocean; for the warm currents, bearing as they do a great abundance and variety of minute forms of life, carry quantities of food for the larger sea animals. Where these warm streams flow, corals grow in luxuriance (p. 251), and their life and growth depend in considerable degree upon the presence of equatorial currents. These interesting little creatures are building extensive beds of limestone in the sea, and it is to them that we owe the construction of the Bahamas, the Bermudas, and a part of the southern end of the Florida peninsula. So in this *indirect* way, ocean currents have aided in the construction of certain coasts.

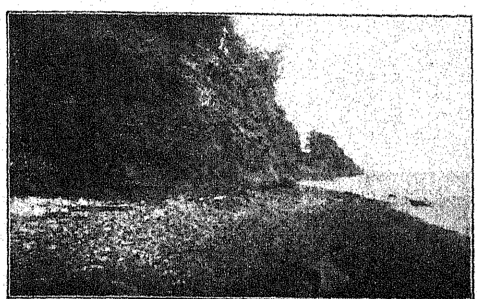

FIG. 133.

Cliff in shale, with beach at base, Lake Erie, N.Y.

Erosion in Lakes. — While most lakes are eventually destroyed by filling, there are in progress during their existence, many changes due to erosion, which in most respects, resembles the action of erosion at the sea-shore.

The great majority of lakes are small; and here the likeness is rather to enclosed bays, harbors, and estuaries than to the exposed coast; but erosion in some of the larger lakes bears a close resemblance to the ocean.

In the large lakes there are great waves and wind-formed currents, but rarely tides. The action of the

Fig. 134.
A spit built by waves in Lake Michigan.

waves and currents is nearly the same as in the ocean; cliffs are cut (Fig. 133), beaches and bars formed (Fig. 134), and sediment deposited in the water. Therefore what is said of marine erosion and ocean sedimentary rocks, holds in the main for lakes. Of course, the animals that live in lake water are unlike those of the sea; and if any of these are preserved as fossils, they serve to tell us whether they lived in lake or ocean water.

AGENTS AT WORK IN THE OCEAN

Chemical Work.	Wave Work.	Tide Work.	Work of Organisms.	Work of Ocean Currents.
Materials dissolved from the rocks by ocean water in contact with the rocks. This, added to dissolved load in the sea, furnishes substances to marine organisms. Rocks weakened by solution.	Strikes the cliffs, and breaks off fragments by the direct blow. Forms sea cliffs; sea caves, and irregularities of coast. Grinds fragments on the beach. Transports these fragments along shore. Undertow carries particles off shore. Cuts back the headlands and fills up indentations. Forms beaches and bars.	Increases zone of wave work. Exposes wet rocks to frost action and air. Grinds ice against the coast. Many tidal currents erode the bottom. All such currents transport sediment.	Sea-weeds, etc., protect the coasts. Buoy up bowlders, so that waves can move them. Clinging to the rocks they rend off some fragments. They take salts out of the water, and build them into rocks.	Modify climate and the temperature of the ocean water. Little work of erosion and transportation done. Move icebergs. Supply limestone-building animals with food.

The Effect of Denudation

The combined action of weathering and erosion is wearing down the surface of the land at a rate slow indeed, yet productive of decided effect in course of ages. If this action had proceeded uninterruptedly, the land would, ere this, have been worn down nearly to the condition of a plain; but as matter of fact, there is always operating an opposite set of forces tending to elevate the land. So the real result in these cases has been deep cuttings into the rocks, forming valleys where the conditions were favorable, and leaving hills between. The existence of soft rocks, or the location of a stream, has determined the lines of valleys, while hills stand up above the general surface of the country, either because they are between the streams, or else because their site is determined by a hard rock.

In the long ages through which these forces have been operating, not only have the lands been carved into hills and valleys, and the coasts changed again and again, but the general land surface has been slowly worn down; thousands of feet of rock have been decayed and moved to the seas; mountains have been planed down; volcanoes have dwindled away under the action of denudation; and the whole aspect of the continents has undergone most profound change.

DENUDATION

Weathering.	Wind.	Underground Water.	Rain.	Rivers.	Glaciers.	Ocean.
Rocks decayed and broken up by chemical changes, solution, action of organisms, frost action, etc. Soils formed. Materials prepared for removal.	Moves loose fragments, and with them batters the cliffs. Drives some of the rock bits into the sea.	Causes changes in minerals. Dissolves them. Brings substances to the surface in solution, which are supplied to the sea.	Furnishes water used in weathering. Supplies water for underground work. Forms the rivers, washes away loose fragments, and furnishes sediment to the rivers.	Cut channels by solution and mechanical work. Remove a load of rock material dissolved and in suspension. Hence lower the land level and help to remove it to the sea.	Locally scour the rocks, and bear away the fragments.	Attacks the land at its margin. Receives and distributes the waste of the land.

The agents of denudation are at work wearing down the land, and in this they are opposed by forces of elevation. To the interaction of these we owe the present land surface, and much of the past change.

The present surface merely represents the *present* stage in the history; and this surface, the product of change, is changing now and will continue to do so just as long as the land stands above the sea in exposure to the air. Denudation is one of the most potent sets of geological forces; for it tears down the rocks of the land, and builds new ones out of their fragments. Being of slow action, it does not attract general attention. For a long time it escaped even the students of nature; but now that we recognize it, we see in it one of the most powerful causes for the changes in the land.

CHAPTER XIII

DEPOSITION IN THE SEA

General View. — While during the movement of rock material from land to sea, some finds temporary lodgement on the land, in river valley or lake basin, most goes to its goal, the sea, where it is spread out over the ocean bottom. The sea is supplied with materials for sedimentation (1) by the wind which blows particles from the land, (2) by the rivers and (3) glaciers, which move over the land, (4) by the waves that beat against the shores, and (5) by volcanoes, which send showers of ash and pumice into the air.

Most of the supply is in the form of fragments which are transported by mechanical means; but much is furnished as chemically dissolved mineral material. This latter may be accumulated in beds directly by precipitation, or it may be taken out of the water by animals or plants, and thus be deposited by indirect means. Therefore on the sea bottom, we have formed sedimentary rocks of three kinds, mechanical, chemical, and organic (pp. 71–98). The former are by far the most important, the chemical sediments are least in quantity.

These ocean rocks are of great interest to the geologist, because the land is largely formed of them. More than one half of the earth's crust is made of rocks that were laid down in the sea, and have since been raised above the surface. They therefore tell us much of former changes, and from them we are able to learn much about the physical geography of the

FIG. 135.

Bowlder beach, Cape Ann, Mass.

past. Moreover, since this action of deposition in the ocean has at all times been in operation, and since on the land we find such rocks formed in all ages of the past, and enclosing remains of animals then living, they constitute a veritable tomb in which is preserved a record of the development of life on the earth. Hence their study is full of interest.

Variation in Sediments along the Shore. — Starting on the coast of Maine and proceeding to the mouth of the Rio Grande, we find what at first seems an interminable and unintelligible variety of sediment along the shore. In Maine, bare, rocky headlands alternate with pebbly and sandy beaches; on some of the beaches the pebbles are small, on others real bowlders (Fig. 135); on some they are of one kind of rock, on others entirely different. In places there are sand beaches (Fig. 31), and in some of the bays or harbors there is a sediment of the finest clay (Fig. 136); and here, along this irregular coast, there is every variety of deposit, from the coarsest to the finest; but the average is coarse.

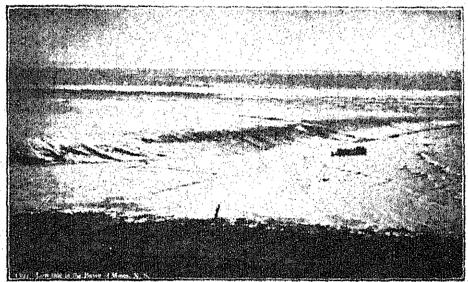

FIG. 136.

Mud flats, Bay of Fundy, exposed at low tide.

On Cape Cod, and from Sandy Hook to the southern part of Florida, pebbly beaches are replaced by sandy. Nearly this entire coast is a sand-bound shore, with here and there stretches of clay where the action of the waves is slight. Not only have the waves thrown up bars, but the wind has added to their elevation by

blowing the sand into dunes. At the end of Florida, the coast is made of coral fragments; yet further, along the shores of the Gulf States, sandy beaches again prevail.

What is seen on these shores is found along nearly all the ocean coasts of the world. On the exposed shore line, where the waves are almost continually in motion, rock fragments at least as coarse as sand will always be found. The reason for this is evident: as fast as the finer particles are rasped off by the waves, they are borne away in slowly moving currents, and deposited at a distance from the shore where the waters are quieter, or else driven into the still bays where they can settle. The coarse fragments cannot be thus transported.

On the coast of Maine the waves are beating against hard rocks, and the rivers carrying little sediment into the sea; so here the materials are mostly derived from the direct attack of the waves on the coast. This attack takes bowlders and pebbles, and therefore the beaches are composed of these materials; but south of New York the rocks near the shore are chiefly soft sands and clays, from which the waves can obtain no large fragments. Here, also, the streams are adding much clay and sandy sediment to the sea. So in this case, even in the most exposed places, the coarsest fragments that can be found are sand bits, and these

make the beaches, because they are left while the currents carry off the finer clay.

Where the coasts are made of corals, the beaches are built of a coral sand or conglomerate (Fig. 137), while the finer bits of coral mud, which are worn off by the waves, are borne seaward and strewn over the bottom.

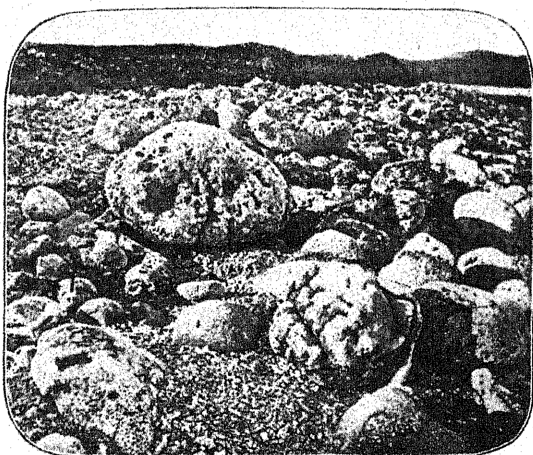

FIG. 137.

Beach on Great Barrier Reef, Australia, composed of coral bowlders.

On the shores of a volcanic island, the coast may be formed of a sand or conglomerate, composed entirely of the fragments ejected by eruptions.

Therefore, the ocean deposits at the coast line are prevailingly coarse, but varying in texture from place to place. They are finest in the enclosed bays, and

coarsest on the headlands which are exposed to the action of violent waves (Fig. 138). They also vary in kind as well as in texture: a granite rock furnishes a different sort of pebble or sand beach from that which is derived from a black basaltic lava, and each of these differs very decidedly from the coral coast. The most striking feature of the shore line is coarseness of rock fragments; and there are many evidences that nearly all the conglomerate and sandstone rocks on the land were deposited in the sea near the coast line, in many cases being fossil beaches, now forming a part of the dry land.

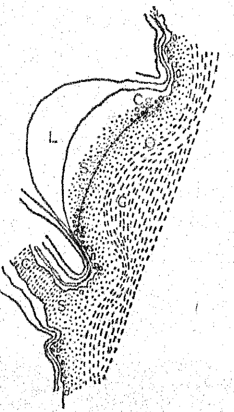

FIG. 138.

Diagram to illustrate variation in sediment along the shore. *L*, land; *O*, ocean; *C*, clay; *S*, sand; *Cg*, pebbles and bowlder beds.

Organic Deposits near the Shore. — *Salt Marshes.* On exposed sandy coasts no vegetation can grow, because the waves continually move the sand, and so plants would soon be uprooted; but where the coast is rock-bound, there is a covering of sea-weed from mid-tide to a considerable depth below the water surface (Fig 139). This serves to protect the rock from the attack of the waves, but it does not succeed in building up any distinct beds of sediment.

In the partly or completely enclosed lagoons of the sea, where ocean waves are not violent, many forms of vegetation find a foothold in the sand or clay of the shallow water. Sediment from streams, or that brought by land wash or tidal currents, is filling these bays or

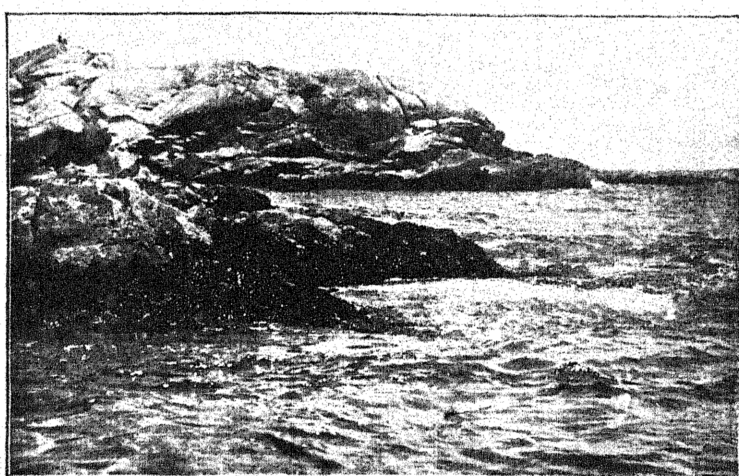

FIG. 139.

Sea-weed (the black part) covering granite rocks at Cape Ann, Mass. View taken at mid-tide.

lagoons; and when the bottom has been thus raised nearly to the surface, various kinds of grasses take root and aid in building up the bottom to the level of the high tide, thus forming a marshy plain (Fig. 140). Through these salt marshes, channels extend, into which the rising and falling tide passes, and then,

overflowing, spreads out as a shallow sheet of water, covering the entire marsh. The salt marsh is always covered with marsh grass, and it owes its existence partly to the action of this vegetation. Sometimes entire bays are converted into salt marsh plains, and on the eastern coast of the United States there are many thousand acres of these.

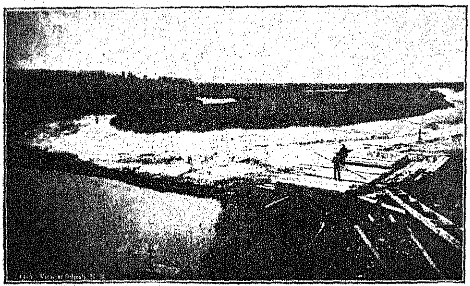

FIG. 140.

A salt marsh on the shores of the Bay of Fundy.

Mangrove Swamps. Salt marshes are treeless, and the plants that help to build them are all of a low type; but in tropical or semi-tropical regions, a form of tree known as the mangrove, is able to grow with its roots in the salt water (Fig. 141). On the coast of Florida there are extensive mangrove swamps, and little by little these encroach upon the sea in a manner similar to that of the treeless salt marshes.

In earlier geological ages it seems probable that other trees had this habit, and perhaps some of the coal beds

have been formed by the life and death of many salt-water-loving trees (p. 460). Certainly, at the present time, the mangrove is making a deposit of carbonaceous matter which resembles some of the layers of coal.

Coral Reefs. Everywhere in the ocean and on the coasts, animals dwell in large numbers, and many of

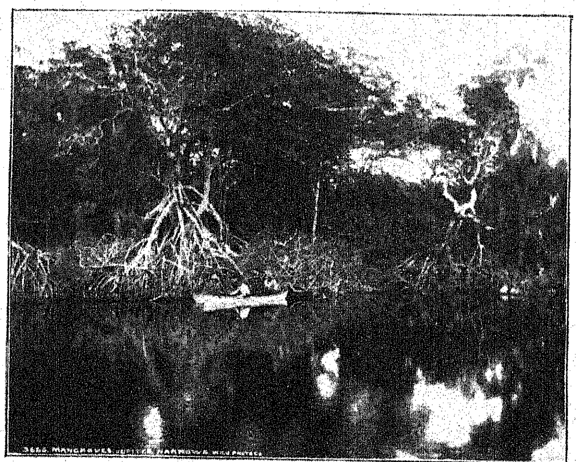

FIG. 141.
Mangrove trees and swamp on Florida coast.

them are able to extract carbonate of lime from the water. This they build into their shells or skeletons, which endure when the softer tissues perish. By this life and death of shell-bearing animals, deposits of carbonate of lime are accumulating on the ocean bottom. There are beds of oysters, and also banks of shells; but by far the most remarkable deposits of

animal origin are those made by the coral polyps, which build extensive reefs.

The reef-building corals are animals which live in colonies. They cluster together, and many individuals combine to build one coral skeleton (Fig. 142). Thousands of these, with beautifully branching forms, or in solid and massive bunches, exist side by side; and in each colony there are many animals, each anchored

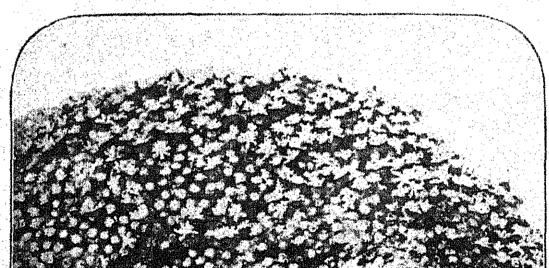

FIG. 142.

A colony of coral polyps, expanded above the solid stony mass.

firmly in place and hungry for food. To thrive they must have extremely favorable conditions.

The reef-building corals cannot live in abundance where the temperature is below 68°, and hence they are mostly confined to tropical or semi-tropical regions. They cannot thrive in water whose depth is more than 100 feet, and will perish if exposed to the air for any considerable length of time. So they develop only below the low tide level. Since the creat-

ures cannot move about to seek their own food, they can thrive only where constantly moving currents bring an abundant supply; nor can they live where the water is muddy, as it is near the mouths of many rivers. The most favorable place for coral

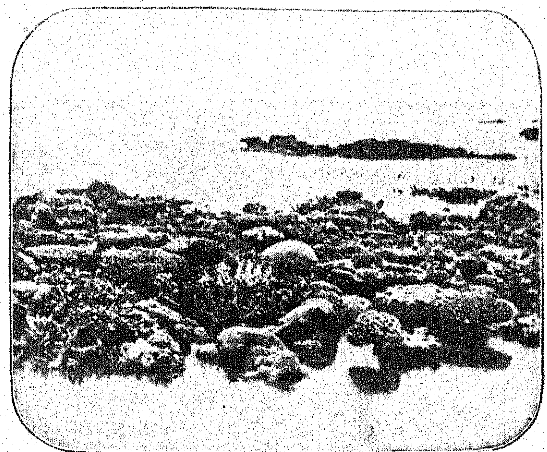

Fig. 143.
Coral life on a part of the Great Barrier Reef, Australia.

growth is in the clear ocean water warmed and moved by the great currents.

While the reef-building coral is so delicate that it is unable to live on most coasts, it is nevertheless found in profusion wherever conditions are at all favorable (Fig. 143). In the West Indies, on the coast of Florida, and among the Bahamas and the Bermudas, we have

illustrations of places where corals are able to grow. There are hundreds of coral islands in the open Pacific. On the coast of Australia there is a great coral reef, known as the Great Barrier Reef, whose length is more than 1200 miles (Fig. 143).

By their life and death, these animals are building up great beds of limestone, but they are doing it slowly, for it is estimated that the average rate of growth of such a deposit is not more than one or two feet a century. Not only are these creatures making limestone beds where they grow, but the action of the waves on the coral shore, rasps off the minute fragments of carbonate of lime, and these are transported to sea as a milky white sediment, which may settle to the bottom many miles from the reef.

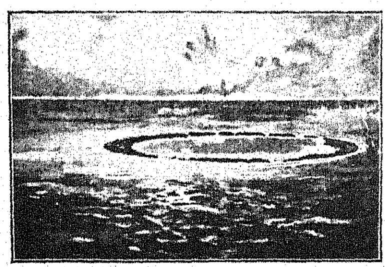

FIG. 144.

Caroline Island in the Pacific. A very perfect atoll.

Coral reefs are of three kinds: (1) The *Fringing Reef*, which exists as a fringe near the coast; (2) *Barrier Reefs*, which develop at a considerable distance from the shore; and (3) *Atolls*, which are circular, ring-like islands of coral in the open ocean, without any other land near by (Fig. 144).

To explain the latter it has been supposed that the atoll began as a fringing reef surrounding a volcano, or other mountain peak, which was raised above the surface of the ocean (Fig. 145). This peak was slowly sinking, and as it sank the coral grew upward, forming first a barrier reef, then, when the peak entirely disappeared, an atoll (Fig. 144).

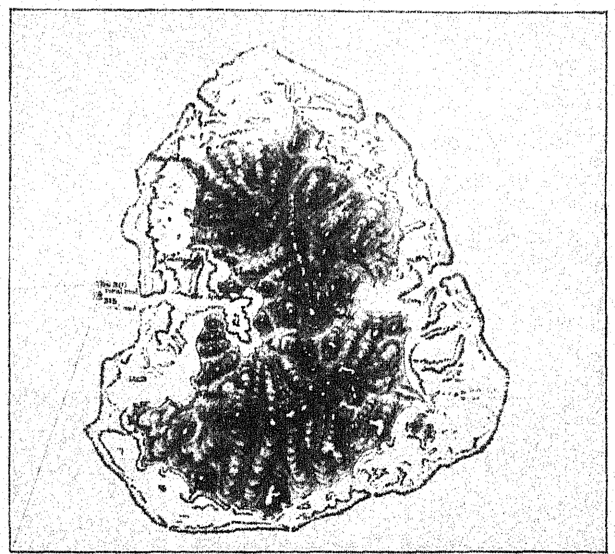

FIG. 145.

A volcanic island in the Pacific, surrounded by a coral reef. The submergence of the island might leave an atoll.

This theory was suggested by Charles Darwin and advocated by Professor Dana; but to many it has seemed improbable, for there is such a large number of atolls and other coral reefs in the Pacific, that if the theory is true, it must be believed that there is a great subsidence in the bottom of the Pacific Ocean in progress over an immense area. This subsidence must be going on at a very

slow and uniform rate; for, if the sinking should become more rapid than the rate of coral growth, the animals would soon be killed by being lowered into deep water. Professor Le Conte has calculated on this theory that there has been a sinking of the bottom of the Pacific over an area 6000 miles long and 2000 miles wide, and that this subsidence has amounted surely to several thousand feet, and possibly to as much as 10,000.

We are no longer required to believe in this slow and wonderful sinking of the sea bottom, for it has been shown that the atolls are capable of other explanation. Briefly stated, the new theory, which has been chiefly advocated by Professor Murray, is that the corals start their growth on some platform below the sea-level, and that upon this a reef is built. This growth may commence on the side of a volcanic cone, or mountain peak, which may either rise above the surface, or be entirely submerged. The bottom of the ocean may be rising, or sinking, or even remaining perfectly quiet.

Therefore, according to this, it is possible to accept the Darwin explanation for some of the atolls, while for others we may rely upon an entirely different theory. The Murray theory certainly explains some atolls, and other kinds of coral reefs, that have been shown to be developing where the bottom of the sea is actually rising instead of sinking, as is required by the Darwin theory. Probably both explanations are needed to account for all reefs.

Variation of Sediment from the Shore to the Deep Sea. —*Mechanical Sediments.* At the very coast line the sediments are naturally coarse, though as has been stated, in some places they are comparatively fine in grain. Since the transportive power of the waves and currents decreases in deeper water, only the lighter fragments can be carried out to sea.

Still, for a distance of several miles from the coast,

there is a constant deposit of land-derived fragments of very fine grain, and over this area a fine-textured mud is slowly forming. The distance to which this may be carried varies greatly with the conditions, in some cases being but a few miles, in others more than one hundred from the shore; but everywhere there is a decrease in coarseness of grain as the distance from the shore increases.

There is also a decrease in the *rate* of deposit, because much less can be carried by a slowly moving current than is accumulated near the land, the source of the materials. Of course, the nature of the mechanical sediment deposited, depends greatly upon the nature of the shore. Near coral islands it is a fine-grained lime mud, near granite coasts it is made of fragments of granite, near volcanic cones it is composed of bits of pumice, etc.

Globigerina Ooze. Beyond the zone of mechanical deposit, although some fragments are constantly dropping to the bottom, these are much less numerous than the shells of those animals which float in the sea water. Therefore, here in the deep parts of the ocean, covering an area greater than one-half of the earth, there is slowly gathering an accumulation of animal remains.

Among these, the most abundant and prominent are the shells of minute floating species, which live in countless millions in the surface waters. Species of

Foramenifera, nearly microscopic creatures belonging to the genus Globigerina, are the most common in this deposit, which is then called Globigerina ooze (Fig. 146). Since almost every bit of this fine-grained mud represents the life and death of a minute animal, one may easily see that it is a deposit whose growth is extremely slow. In addition to the Globigerina, there are other organic remains, together with bits of pumice. Sometimes the ooze contains more of other species than of Globigerina, and it is then named according to the predominant type of animal (diatomaceous ooze, pteropod ooze, etc.).

FIG. 146.
Globigerina ooze, enlarged by the microscope.

How long this immense bed of ooze has been gathering, and how great is its depth, cannot be stated; but dredgings in the ocean prove it to be one of the most widespread deposits on the surface of the earth. Beds of chalk were apparently formed in the deep sea away from the neighborhood of large land areas, very much in the same manner that Globigerina ooze is gathering to-day (Fig. 147).

Red Clay. In the deeper parts of the ocean, even this slowly accumulating deposit is absent; for at these great depths, the ocean water is able to dissolve the carbonate of lime of the shells as they settle. Therefore the only portion which reaches the bottom is the minute remnant of insoluble impurities. To this is added fragments of pumice from volcanic eruptions, for this rock material is falling over the surface of every ocean, and sinking to the bottom whenever it decays or becomes water-logged.

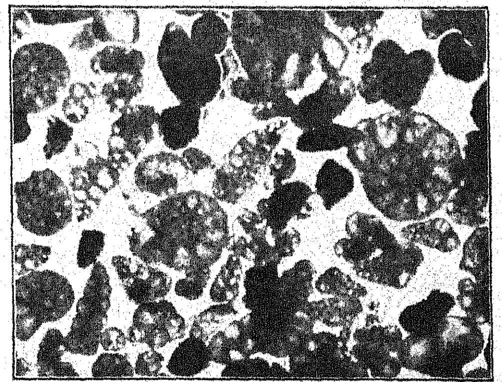

FIG. 147.

Photograph of a microscopic enlargement of chalk from Iowa, showing shells of Globigerina.

This very fine-grained clay accumulation is colored red by iron compounds from the volcanic ash, and from particles of meteorites which have burned in the air and dropped into the water. So slowly are these red clay deposits gathering, that fragments of meteorites have been found even in the few places where dredgings have been made. Red clay rocks are not known to exist among the strata that form the continents, and so it seems fair to conclude that these have never been submerged in really deep water. This interesting red clay is estimated to cover an area of ocean bottom equal to fully 50,000,000 square miles.

CHAPTER XIV

STRATIFICATION

Nature of Stratification. — If we examine a series of rocks that have been formed in the sea, such as any section of sedimentary strata, we find them arranged in layers. Upon looking closely we are able to discover both small (Fig. 149) and large layers (Figs. 148 and 167), just as if a series of books were placed in a pile. Each book, it may be, is different from every other, and the covers differ from the leaves. Each of the larger divisions of the rock, which might be likened to the book itself, would be called a *bed* or *stratum* (Fig. 148), and the small layers comparable to the leaves, would be named *laminæ* (Fig. 149). The larger layers, or strata, would be found to differ from one another considerably. We might even discover a bed of shale resting upon a bed of limestone, and above this a sandstone or even a conglomerate; but the laminæ differ less markedly, and may all be of one kind (such as shale, etc.).

Cause of Stratification. — *Minor variations.* These strata and laminæ represent differences in the conditions of accumulation. There are many ways in which such differences may be caused. For instance, in the delta of the Mississippi, there is a gradual and rather rapid accumulation of fine-grained sediment, brought down by the river. Ordinarily it is a brownish mud, but when its tributary, the Red River of Arkansas, is in flood, the color of the muddy water is changed from brown to red; and during this time the sediment that is deposited upon the delta is of reddish hue. So, according to the condition of the flood, there are deposited alternate layers of red or brown colored sediment, which in other respects are alike.

Fig. 148.
Beds of stratified rock. Hard sandy layer in foreground is seen projecting from left side of gorge.

On many coasts where rivers are emptying their waters, the sediment they bring is ordinarily muddy;

but when the rivers are in flood, what they transport often changes to a coarser material, perhaps even to a sand, because then the river water is able to carry coarse fragments. Here then, at this time, layers of sand are deposited, while during ordinary conditions

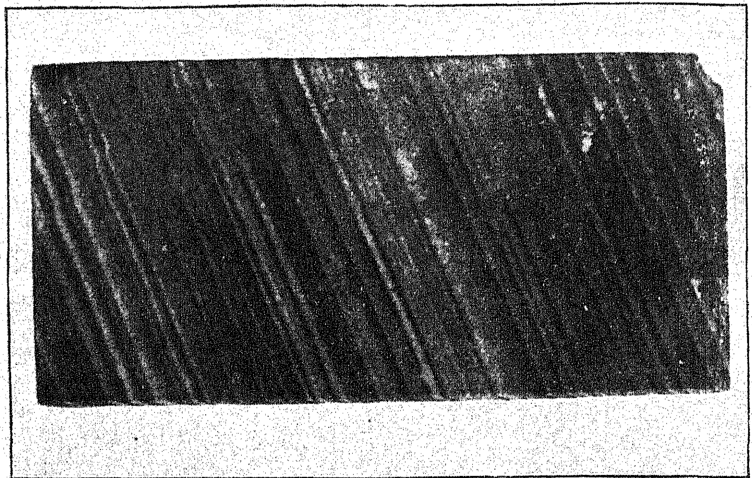

FIG. 149.

Lamination in stratified rock. Tiny fault in upper left-hand corner.

the deposit is of clay, and so layers of sand and clay alternate in the growing accumulation.

Again, rivers often change their point of overflow, particularly when they enter the sea over deltas. At one time the sediment may be that which the river is carrying, while later, when the mouth of the stream

is changed to another place, the material deposited is that which the waves furnish.

Another way in which these small variations may be caused, is by the ordinary changes of weather, from quiet to storm, and from the moderate summer to the extreme conditions of winter. When waters are agitated by waves, and moved by the wind currents that storms produce, the fine particles of sediment are floated away from the muddy coast, and only the coarser allowed to settle to the bottom; but when the water is stiller, the coarser fragments are either not supplied or else not transported so far, and in this case the sediments are partly, if not entirely, made of fine fragments which build a layer of mud.

Therefore, as a result of this difference in rate of movement of the water, the texture of the beds may vary. On one day mud may settle, during the next a layer of sand, and on the following these two layers may be covered by a thin deposit of pebbles; and so, from day to day, the accumulation on the ocean bottom near the shore, may be made to vary considerably. In winter the water is on the average roughened more than in summer, and hence the deposits that accumulate during the winter season, will in general be coarser than those made during the summer.

Greater variations. To account for the larger beds or strata, more permanent changes are necessary.

Perhaps a river mouth is shifting, so that upon a thick layer of sand, which has been built by wave action, a deep layer of mud is deposited where the river pours forth its sediment. Streams like the Yellow River of China not uncommonly shift their mouths over distances of many miles, each time introducing a change in the kind of material that is forming on the bottom.

Or again, corals growing in clear, warm ocean water may become exterminated by a slight change in the conditions, introducing muddy or cold water. So a bed of limestone, constructed out of coral remains, may abruptly cease and be covered by an accumulation of clay.

A third important cause is the change in the land level. In the later pages, we shall find that coasts are constantly changing as a result of movements of the land. Some shores are sinking, others are rising, and from these changes there are conditions introduced which now favor the deposit of conglomerate, now of sand, and later of clay or even limestone.

A study of the rocks reveals infinite varieties of this nature. Layers of vegetable matter, which grew on the land, are buried beneath ocean sand or clay, showing that the coast was slightly lowered. In some sections of strata nearly the same conditions seem to have prevailed for long periods of time. In such cases

there are accumulated thick beds of limestone, sandstone or clay. But at the opposite extreme, there are cases in which changes are so frequent, that in every few feet new conditions were evidently introduced.

Position of the Strata. — In ocean or lake, the fragments settle under the action of gravity, and arrange themselves in accordance with the outlines of the bottom. In most strata there is one portion in which the accumulation was more rapid, and here the bed is naturally thickest. This place of most rapid deposit is that at which, for some reason, the supply was greater than at other portions of the stratum. It may be opposite a river mouth, or where the waves or currents are most active.

As we recede from this place of greatest accumulation, the stratum thins out in all directions, often rapidly, again more slowly, in every case gradually merging into another bed composed of coarser or finer material, or of fragments of an entirely different kind. For instance, the sand of the seashore imperceptibly passes into the clay of the off-shore bottom. There is no place where the deposit of sand ends and that of the clay begins, the boundary being very indefinite and variable, depending upon the force of the currents which are moving the particles.

As the layers are thickest in one part of the stratum,

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As the layers are thickest in one part of the stratum,

thinning out in several directions, the strata are usually more or less lens-shaped or *lenticular* (Fig. 150), with somewhat indistinct boundaries. Not only do they vary in these respects, but some beds are accumulated much more rapidly than others; and therefore, in the same length of time, there may be deposited many feet of conglomerate, while the depth of the clay accumulation near at hand may amount to only a few inches.

On the average, the ocean bottom is fairly level, and so the layers that are deposited on it are usually nearly

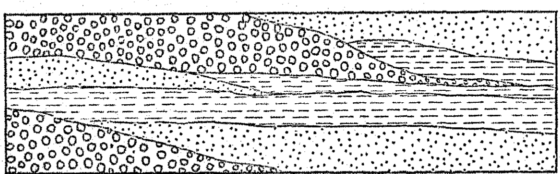

FIG. 150.

Diagram to show lenticular form of beds. Vertical exaggerated. Boundary lines sharper than natural.

horizontal, but not always, for there are places where the bottom is irregular, and in such, since the layers conform to the outline of the ocean floor, they are not accumulated in a horizontal position. So sedimentary rocks, while generally deposited in *horizontal layers*, may in some cases be formed with the beds tilted at a considerable angle. In some parts of the bottom, the angle of slope may be as steep as that of the mountain side, but such places are exceptional. When built into

the land by those movements of the crust that form mountains, these layers are sometimes very much disturbed and moved from their position, being bent and tilted at all angles, even to the vertical (p. 283).

If a series of strata are in process of deposition in the ocean, the lowest is first formed and is hence the oldest (Fig. 151). Therefore when these are added to the land and exposed to the eye, we usually feel certain that the lowest bed is older than the ones above it. This *order of superposition*, as it is called, is sometimes disturbed when the rocks have been folded excessively, or broken, and then moved one over the other (Fig. 173). Then, as a result of this unusual disturbance, the older rock may actually lie on a younger one; but these cases are rare.

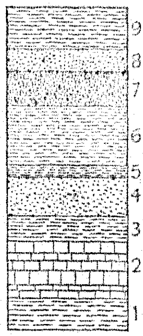

FIG. 151.
Diagram to illustrate order of superposition. Figures indicate order of deposition.

Most Sedimentary Rocks deposited in Shallow Water. — *Absence of deep-sea deposits.* On the continents the most common rocks are sedimentary, and the greater number of these were formed in the sea. We know this because they contain fossils of ocean animals that were entombed while the rocks were accumulating. Since the greater part of the ocean is very deep, one might suppose that the sedimentary strata of the land would include many deep-sea deposits; but

the reverse is true, for on the land there are scarcely any strata that were laid down in the deep sea. Excepting in a few localities, the sedimentary strata are either limestones or fragmental rocks made of particles of waste from the land.

Evidence of Shallow Water Origin. Among these fragmental rocks we often find distinct evidences of formation in shallow water, and in some cases that

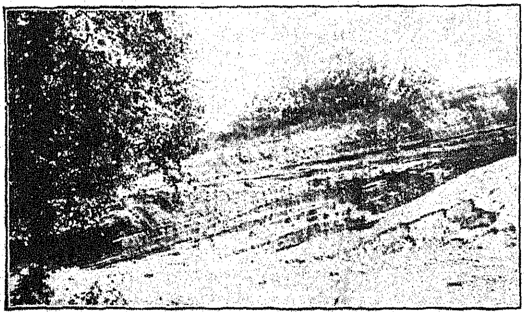

FIG. 152.

Cross-bedding in a gravel bank.

they were deposited at the very shoreline. Sometimes the strata have been laid down at various angles, giving the appearance of great disturbance. This is known as *cross* or *current-bedding* (Fig. 152), and is due to rapid variations in the direction and force of the currents that were bringing the sediment. When present, cross-bedding is usually found in sand or gravel beds, and at any time we may see it forming

where streams are entering quiet bodies of water. Such conditions are found only in shallow water.

In some cases, layers of rock have been cut by stream channels (Fig. 153), or washed by the rain while they were forming, which would not have been possible unless they had been deposited near the shore. Where sedimentary rocks have been carefully studied, as in certain coal mines, actual river or rivulet valleys are sometimes revealed.

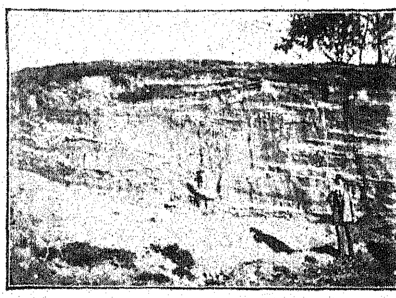

FIG. 153.

Cross-bedding in gravel bank. Small stream valley cut in the gravel in middle of the bank, and later filled with other gravel.

On the surface of the layers one often finds the imprints of *rain-drops* (Fig. 154), or the *footprints* (Plate 12) of land animals, or cracks of shrinkage caused by the drying of the mud, exactly as *mud cracks* are formed at the present day, when after a summer shower, the water in the small road-pools evaporates, leaving the mud dry and cracked. These effects could be caused only where the rocks were accumulated on the shore, and exposed to the air at ebb of tide.

Often there are fossil beaches and wave-cut cliffs preserved among the sedimentary rocks; and even more common than these, the surface of the layers

PLATE 12.

Footprints of reptiles of Triassic age on a shale from Connecticut River valley.

is often marked by a series of undulations, which are known as *ripple marks*. These are caused by the rising and falling of the waves. They can be formed only where the depth is so slight that the effect of the waves is felt on the bottom. Ordinarily this depth is less than a score or two of feet. On the sandy or clayey bottom of lake or sea-shore, ripple marks may

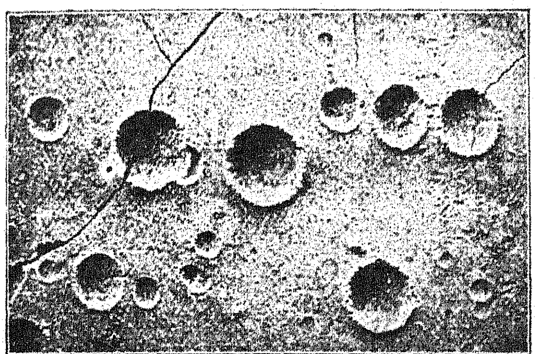

FIG. 154.
Rainprints on a surface of mud.

be seen forming to-day, giving rise to outlines which in no respect differ from those preserved in the strata.

Change in Level of Land and Sea Bottom. — While the majority of sedimentary rocks are thus of shallow-water origin, we nevertheless find accumulations of sedimentary strata with a depth of thousands of feet, one layer over another. So we have the apparent anomaly of a great thickness of layers, each of which

was deposited in shallow water. To account for these two apparently contradictory facts, we can only conclude that at the time of their formation the ocean bottom there was slowly sinking, and that the rate of subsidence was never so great as to produce really deep water, but always maintained a relatively shallow sea.

Of these great and slow changes in the level of the land and the sea-bottom, there are other evidences (see next two chapters) ; but this alone would seem sufficient. For some reason, as yet unascertained, the bottom of the sea has in some localities slowly subsided for a long time, and as it settled, sediment has naturally accumulated, forming a series of layers which attain great depths, and are often composed of rocks of very different kinds. Then the reverse process has come about, and the sediments thus accumulated have been raised to form part of the dry land. In various parts of the earth, there are places where these two opposite movements are even now in progress (Chapter XVI.). The fact that ocean formed sediments are so abundant even on the highest land, is proof of great and widespread uplifts of the sea-bottom.

CHAPTER XV

CHANGES IN THE STRATIFIED ROCKS

Consolidation of Rocks. — The sediments of the ocean are mostly deposited in loose, unconsolidated condition. Being formed one layer upon another, in the course of time many of the sedimentary rocks become buried beneath other strata to a depth of hundreds and even thousands of feet. Under the pressure of this load, some of the finer layers become compacted into a solid rock.

Usually this pressure has been accompanied by another and more potent cause of consolidation; namely, the deposit of some substances from solution, by means of which the fragments are cemented together. Even at the surface this cementing process may sometimes be seen.

Percolating water bearing in solution salts of iron or carbonate of lime, often transforms a gravel bed to solid rock by depositing a cement of the dissolved substances. Also, on coral islands, the hills of coral sand are sometimes made into rock by the action of

the rain water, which dissolves a little carbonate of lime, and soon afterward deposits some of it as cement. This action is well illustrated in the Bermuda Islands (Figs. 63 and 155).

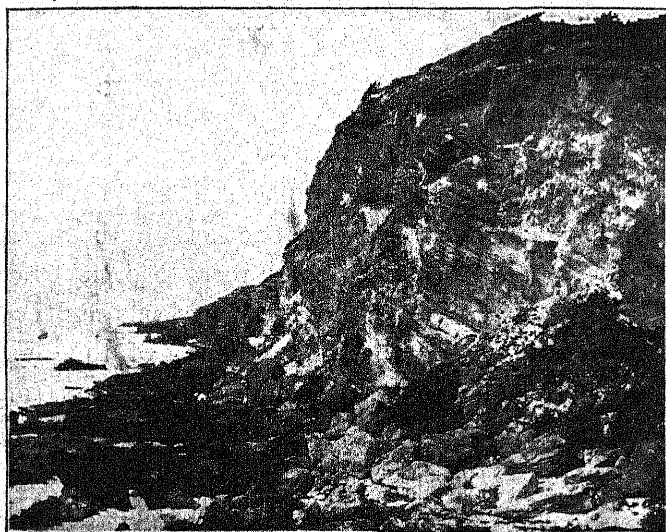

FIG. 155.

Coral sand in Bermuda, cemented to rock by rain-water action.

Water is always moving through the rocks, and as it goes, doing some chemical work. One of its important actions is to dissolve here and deposit there, and thus cement the rock particles together. This action of solution and deposition becomes stronger if the water is warm or hot, for then chemical action is

naturally more pronounced. Then even silica may be made to serve as a cement, and a sandstone be transformed to a dense, solid quartz mass. Indeed, by the action of hot water, metamorphism may begin, and a series of very complex changes commence, by means of which the original rock is finally altered beyond recognition. Generally the cementing of rocks is the result of several agencies, among which water is the most essential.

Several substances are common as rock cements, particularly carbonate of lime, the salts of iron and silica. Nearly all the limestones, many of the clay rocks, and some of the sandstones are cemented by carbonate of lime. Iron as a cement is most common in sandstones, and less frequently binds together the fragments of clay rocks. The same is true of silica. Frequently two or three of these substances unite to cement the same rock. Because of this ready action of water, nearly all the sedimentary strata of the land are changed from their original loose, incoherent condition, to solid rock.

Concretions. — In the geyser basins of the Yellowstone Park, some of the silica brought to the surface in the hot water, is gathered together into balls which are growing in size by constant additions. These more or less spherical accumulations of silica are known as *geyserites* (Fig. 43).

On many shores where the water carries much calcite in solution, a part of this is deposited so as to form tiny spheres of

carbonate of lime. These spherical grains, usually smaller than the head of a pin, are *oölitic grains* (p. 95), and sometimes rocks are made of them, which are then called *oölites* (Fig. 41).

Besides such concretionary masses, there are some which are formed in the rocks after these have been deposited. They are called *claystones* or *clay ironstone concretions* (Figs. 156 and 157), and are particularly common in strata of clay in which there is considerable iron or carbonate of lime. From the cliff of clay

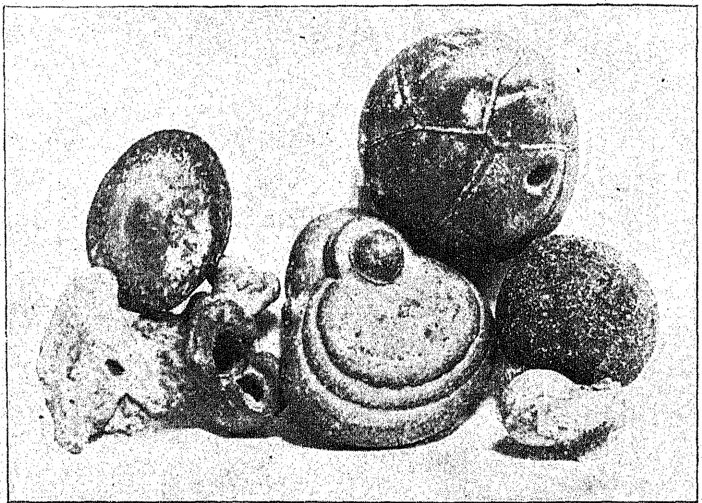

FIG. 156.

A group of claystone concretions slightly reduced.

rock one may often see them projecting as spherical, oval, or disk-shaped masses, sometimes tiny, but often many pounds in weight. They project beyond the rest of the cliff because they are more compact than the enclosing stratum. They may, indeed, be solid rock-like masses, enveloped in soft clay. Then their forms are sometimes very irregular and even fantastic. Not uncommonly

they imitate the shapes of animals, and many have taken them for petrified substances.

If the concretions are carefully examined, they will be found substantially like the enclosing rock, and often built around some foreign substance, such as a shell, pebble, or the stem of a plant. Their origin seems to be that of slow accumulation about these foreign centres, which serve as places where the cement of the rock is gathered in greater quantities than in the surrounding area (Fig. 158).

It is as if by some force, which may be called the *concretionary*

FIG. 157.

A group of concretions about one-sixth natural size.

force, the cement is deposited from the water with greater ease here than elsewhere. The process is somewhat analogous to the growth of a crystal. The same tendency for like substances to accumulate about centres, is seen in chalk and in other beds of carbonate of lime, where accumulations of silica are built up into concretionary nodules of *flint*.

Joint Planes. — *In Sedimentary Rocks.* One of the secondary structures in the sedimentary rocks, is the breaking or cracking along planes, without any move-

ment of dislocation. The rocks are simply split or cleaved, as if they had been cut by a saw (Fig. 159); and these smooth-sided joints often extend over considerable areas with nearly the same direction. Usually there are two sets of joint planes, reaching nearly vertically into the earth, and cutting one another almost at right angles. This, with the bedding planes, causes the rock to be broken naturally into blocks which are often nearly perfect rhombs. Sometimes the joint planes are close together, but more commonly several

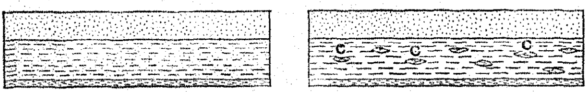

FIG. 158.

Diagram to illustrate origin of concretions. Layer on left contains substances disseminated (indicated by dots), which in right-hand figure are accumulated in bunches or concretions.

feet apart, though even in the same rock we may see the two extremes side by side.

In Igneous Rocks. Not only are sedimentary strata thus cut by joint planes, but in igneous and metamorphic rocks the same is seen. In some igneous rocks, particularly basaltic lavas, like those of Fingal's Cave on the Isle of Staffa (Fig. 160), off the Irish coast, and in the Palisades of the Hudson, there is a remarkable form of jointing, which cuts the rocks into columns with a variable number of sides, though prevailingly with six (Fig. 161). The rock looks like

a honeycomb. These igneous rock joints appear to be due to the contraction of the rock in cooling. When they first solidify, the lavas are very hot; then, as they cool, they begin to contract, and this causes the rock to split into hexagonal columns. Joints of cooling of a somewhat different type are

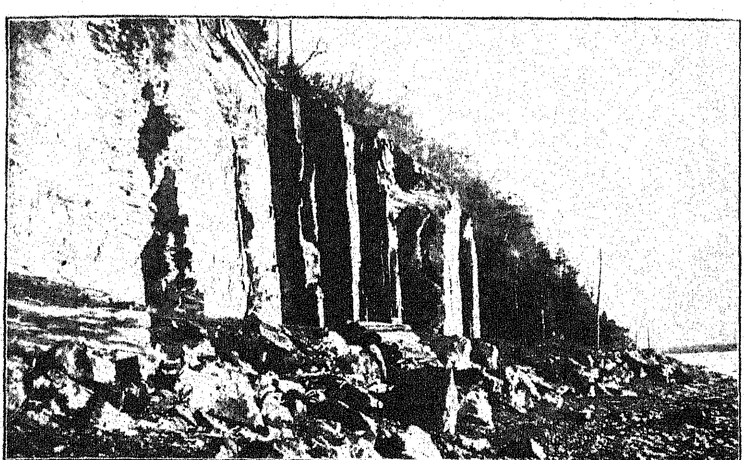

FIG. 159.

Joint planes on the shore of Lake Cayuga, N. Y.

also seen in granite and other igneous rocks (Fig. 162).

Cause of Joint Planes in Sedimentary Rocks. It is more difficult to account for the joints in the sedimentary rocks. By experiments with glass, it has been shown that a twist, or torsion, will finally snap

the glass, producing rhombic joints. As quarrymen well know, many rocks, and indeed most, are in a state of strain analogous to that produced by twisting. In many places this strain is being slowly increased, for the rocks of the surface are continually moved and changed in position by contractions of the crust[1] (see p. 283).

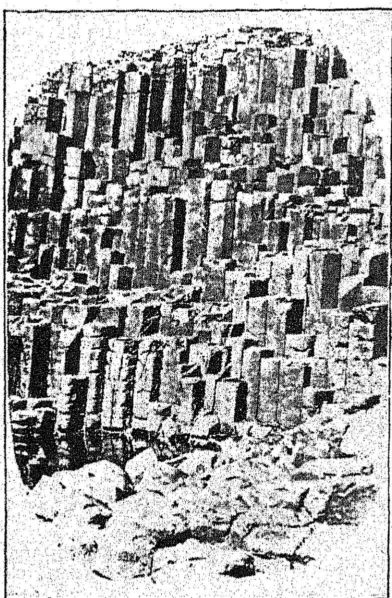

Fig. 160.
Columnar joints, Isle of Staffa.

So it is thought that this straining or torsion of the strata may have caused many, and perhaps all joints in sedimentary rocks. In support of this view it may be said, that those strata which have been most twisted, are crossed by the greatest number of joints, and brittle rocks are better jointed than the more plastic ones.

[1] In quarries a rock layer sometimes bends when the beds above it have been removed; and the blocks that are quarried out sometimes expand so that they could not be put back in the same space.

A theory has also been suggested to the effect that the joints may have been formed by earthquake shocks passing through rocks already strained, but not enough so to cause breakage. In order to test this hypothesis by actual experiment, glass has been twisted not quite up to the breaking point. It has then been jarred, and a breaking has followed which has caused the

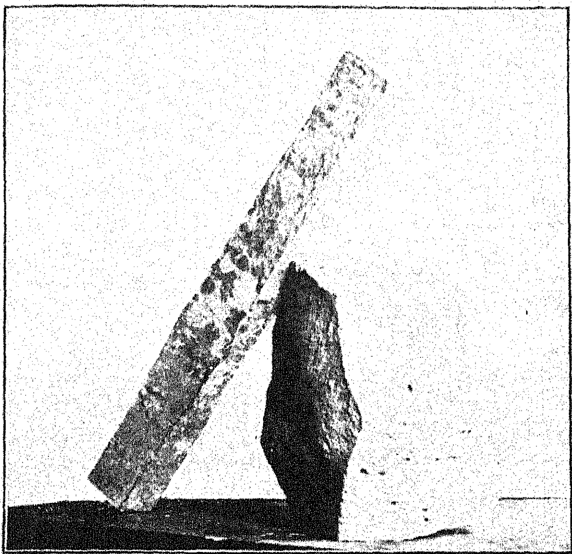

FIG. 161.
Columnar joints of basaltic lava. Long one from Isle of Staffa, short one from the Palisades of the Hudson.

glass to crack in such a way as to produce rhombic blocks, just as we find in the jointed rocks.

There are two other possible causes for joints. Many of the sedimentary rocks have been deeply buried; and as the rate of increase of temperature is one degree for every fifty or sixty feet of descent, those that have been covered to a depth of several

thousand feet may have become so warm, and so fully expanded, that when they were later cooled by the removal of the blanket of overlying rock, their contraction caused them to break by jointing. These rocks were also filled with water; and when they came near the surface, and some of this was drained out, there was a second possible cause for a decrease in bulk and consequent contraction.[1] It is not impossible that in different places all these causes have been at work to produce joint planes; but the last two seem to be of the least importance.

FIG. 162.

Joint planes in granite quarry in Missouri.

Regularity of the Plane. The joint planes cut the rock in perfectly straight courses, quite unlike the way in which rocks would break at the surface. There are no irregular and jagged edges, but perfectly smooth faces, the crack sometimes clipping off the ends of

[1] In a clay bank the drying by loss of water often produces irregular jointing.

pebbles, even those of tiny size, in preference to going around the ends. To explain this it is necessary merely to remember that when these joints were formed, there were layers of rock above them, which pressed down with so much weight that the easiest plane of breakage was the shortest, not the ragged, irregular crack, such as would result if the rock had been broken in the air, where the pressure upon its surface is so slight.

Folding of Rocks. — *Terms Used.* While many of the sedimentary strata have been elevated above the sea in nearly their original horizontal position, some have been moderately disturbed, and many, particularly those in mountains, have been tilted and folded until they stand on end in a nearly vertical position.

Certain terms used by geologists in describing these folded rocks must be introduced here. Where strata are exposed to the air in a cliff or ledge, or any other *natural* exposure, they are said to crop out, and the rock is called an *outcrop* (Figs. 139, 167, etc.). If the stratum is more or less tilted, the direction in which the bed extends into the earth is called the *dip* (Fig. 163). This is the inclination of the surface of the *layers*, not necessarily of the rock face. It is as if we inclined a book away from us and considered the leaves to be strata. The dip in this case would be the inclination of the leaves, or of the covers.

The horizontal line at right angles to the dip, is called the *strike* (Fig. 163). This is the line which corresponds to the horizontal edge of the inclined book cover.[1] On a pitched roof the inclination of the face of the roof corresponds to the dip, the ridge pole to the strike. Being horizontal, the strike is measured by compass direction; and as the dip is at right angles to this, its inclination is measured in degrees from

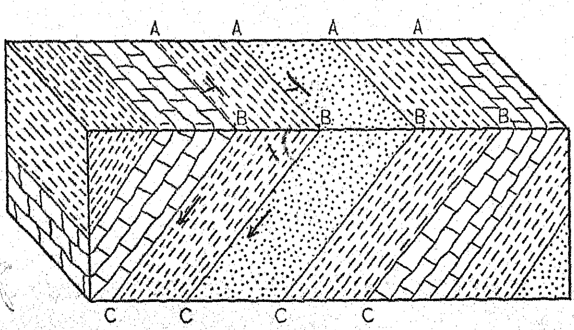

FIG. 163.
Diagram to illustrate strike (*AB*) and dip (*BC*).

the horizontal (0° for horizontal, and 90° for vertical). The direction of the dip is measured by compass, and it is one of two directions at right angles to the strike (Fig. 164).

The Folds. In the course of their disturbance from the horizontal position, rocks are very often bent or

[1] Strike can be defined without reference to the dip as follows: it is a horizontal line in the plane of the bedding.

broken. The simplest fold is the *monocline* (Fig. 165), in which, between two nearly horizontal areas, there is an inclination of the layers. It is therefore a fold with an inclination in one direction only.[1]

Where the folding results in a dip in two directions, we have either an *anticline* or a *syncline* (Fig. 166), the first being an upfold, the second a downfold.[2] The direction in which the fold extends is the *axis*. Very often anticlines and synclines are *symmetrical* (Fig. 167); but much more commonly *unsymmetrical*, with one side or *limb* dipping more rapidly than the

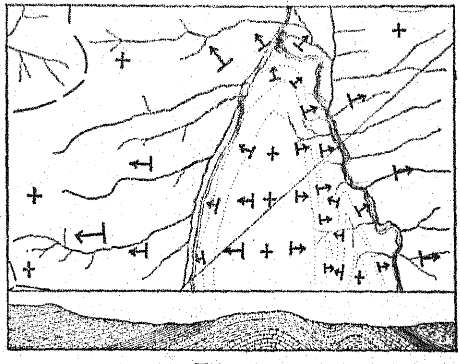

FIG. 164.

Map showing symbols used to indicate dip and strike. Cross indicates horizontal rock. Arrow points in direction of dip. Line at right angles to this shows strike. Length of arrow shows amount of dip. Section at bottom represents actual structure.

[1] The term *monocline* is sometimes used to define one part of a more complex fold, such as one-half of the anticline or the syncline. It is also used to indicate the single inclination of tilted rocks on one side of a fault plane. These are really distinct monoclines, but not monoclinal folds.

[2] There are few mistakes more common on the part of students of geology than to suppose that an anticline is synonymous with a hill, and a syncline with a valley. This is often so, especially when an anticline is complete; but where denudation has been in progress, we often find that the anticlinal elevation has been reduced to a valley, and the syncline to a hill (Fig. 182).

other. In some cases this goes so far that the folds are *inverted* or *overturned*[1] (Fig. 168). Indeed, some rocks are so excessively folded that they are really crumpled, just as we might crumple a piece of paper (Fig. 169). This crumpling of rocks is particularly common among those which are metamorphosed, and is produced deep down in the earth.

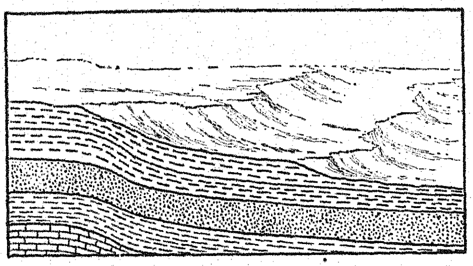

Fig. 165.
Section through a monoclinal fold.

It seems strange to think of rocks as folding like so much paper; but even brittle substances can be bent and folded if they are prevented from breaking by a great pressure on all sides, and if the change is slowly introduced, as seems usually to be the case in the folding of the earth's crust. It is somewhat like the action of ice, which, though naturally brittle, may be easily bent if this is

[1] It is not to be understood that rocks are commonly *overtoppled;* for it is probable that these overturned folds are always formed deep below the surface. Even if they were produced at the surface, it is to be remembered that mountain folds take shape with extreme slowness, and that, as they grow upward, they are also being cut down by denudation; so that they do not reach the elevation that they would attain if nothing interfered. Thus an overturned fold may be formed without any actual overtoppling.

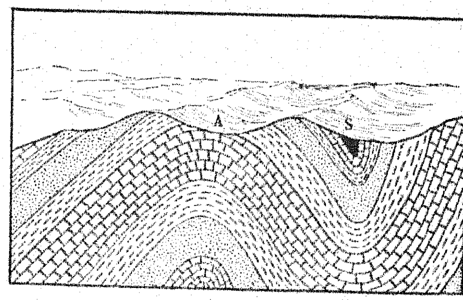

FIG. 166.
Section through an anticline (*A*) and a syncline (*S*).

done slowly enough. Under these conditions, rocks are actually made to fold by a slow stress, constantly and irresistibly applied. In thinking of the behavior of rocks so situated, we must dismiss our conception of their action as we see it at the surface. Here, there is nothing to prevent their breaking as brittle bodies do; but deep in the earth, the pressure makes actual breaking less easy than bending, which to be sure may be accompanied by minute fractures.

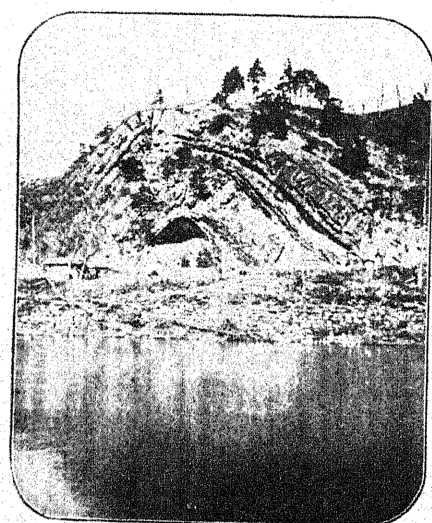

FIG. 167.
Photograph of a symmetrical anticline.

Faulting of Rocks. — *Nature of the Fault.* When the strata are subjected

to strains and stresses, they sometimes break or fault, and move on one side of the plane of breakage, or as it is called, the *fault plane* (Fig. 170).

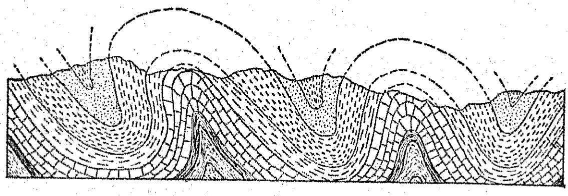

Fig. 168.

Section of unsymmetrical and overturned folds.

Probably when rocks are bending and folding deep down below the surface of the earth, they are often

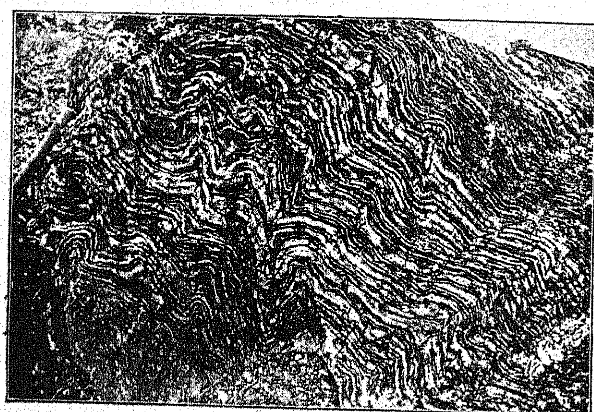

Fig. 169.

Photograph of crumpled rock.

being broken and faulted at the very surface. Certainly there are some folds which on one of their

ends may be seen to change into actual faults; and the same kind of strains, applied to different classes of rocks, will cause the brittle to break while others bend.

It is not to be understood that faulting is confined to the surface, for there are some great faults that

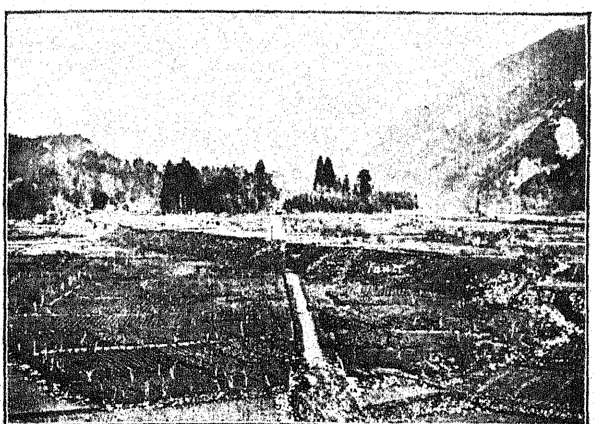

FIG. 170.
Photograph of a fault slip which caused the Japanese earthquake of 1891.

appear to extend far down into the earth. Sometimes the total displacement amounts to only a fraction of an inch, while again it may be measured by thousands of feet. In the great faults, the breaking and movement have probably been accomplished very slowly, just as in the case of rock-folding. Even now in Japan (Figs. 170 and 219), and in various other parts of the

world, great faults are developing; and every time the rocks slip for a distance of a few inches or feet, a disastrous earthquake shock extends over the neighboring country.

Terms used. In the fault, the plane of breakage is called the *fault-plane* (Fig. 171). Sometimes the fault-plane extends vertically into the earth, but usually it is inclined from the vertical, though it almost always dips underground at a high angle. The dip of the fault-plane is called the *hade*, but the *angle of hade* is measured from the vertical, not from the horizontal, as is the dip of the rock stratum. Examining a faulted area, we find that a given layer stands on the two sides of the fault-plane at different levels. The space by which the two ends are separated, or the vertical distance between them, is called the *throw*. The side that is uppermost is called the *upthrow* side; that which is down, the *downthrow*. Whether one side went up or the other moved down, cannot usually be told, but almost always the movement is on one side only.

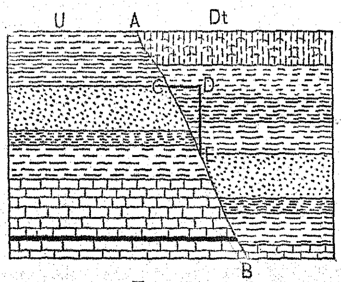

Fig. 171.

Diagram of a fault. *AB*, fault-plane; *DE*, throw; *U*, upthrow side; *Dt*, downthrow side.

Kinds of Faults. Where faults cross horizontal

rocks, their effect is relatively simple, but when they cut inclined or folded strata, it is often exceedingly complex. They produce a variety of effects accord-

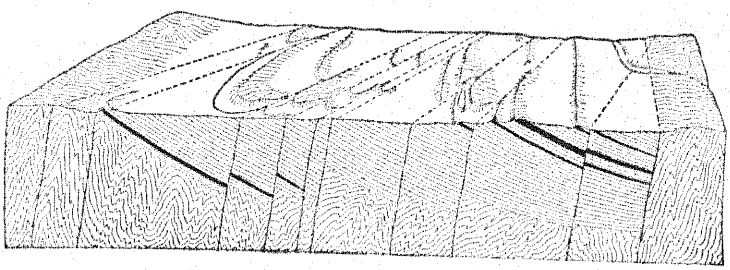

FIG. 172.

Diagram of faulted region in Connecticut valley, Conn., showing section of faults and the erosion surface with the discordance of strata on the two sides of the fault-planes.

ing to the direction they pursue and the angle of their hade. When a faulted region is planed down

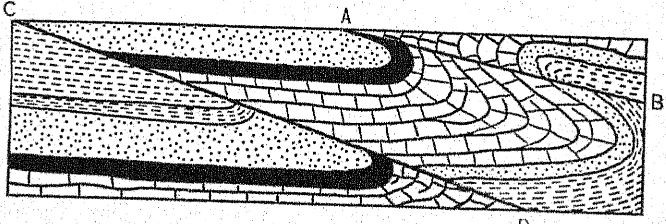

FIG. 173.

Cross-section of overthrust faults. Thrust planes, *AB* and *CD*.

by erosion, the strata are raised in sharply discordant positions, so that it is often difficult to piece them together and to see what their original position

was (Fig. 172). This is especially true where there are numerous faults near together. Sometimes many faults running in parallel directions produce the effect of *step faults* (Fig. 174).

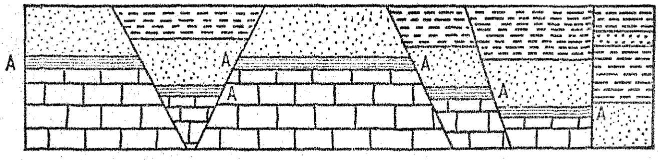

Fig. 174.

Diagram of normal faults. Step faults on right.

If the angle of hade is great, and approaching the horizontal, the strata are thrust over one another horizontally. This condition is known as the *overthrust fault*, and the plane of faulting is called the *thrust*

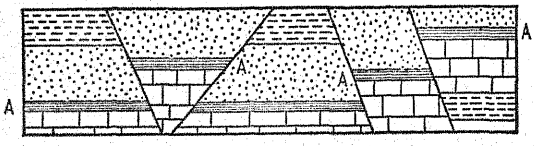

Fig. 175.

Diagram of reverse faults.

plane (Fig. 173). This may cause the bodily transfer of great blocks of strata horizontally for a distance of thousands of feet; and an overturned fold may change to an overthrust fault.

Two of the most common dislocations are those

which are called *normal* (Fig. 174), and *reverse* faults (Fig. 175). When the direction of the hade is toward the upthrow side, the fault is reverse; when it is toward the downthrow side, it is called a normal fault. In the reverse fault a vertical shaft will pierce the same layer twice, in the normal but once. Without the use of illustrative models it would hardly be profitable to pursue the subject of faulting further.

CHAPTER XVI

CHANGES IN LEVEL OF THE LAND

Historical Evidences. — One of the most striking results of the study of geology, is the proof that the land is very unstable in relation to sea-level. The crust appears to be in constant but slow movement. Of this there are two classes of evidence, — one historical, the other geological.

Although the latter is by far the more important, the former merits consideration, if only because of our interest in such a testimony from human records. Of the many scores of instances which have been recorded in various parts of the earth, but two or three are mentioned here.

The evidence of the movement of the land that has been most frequently described, is that of the temple of Jupiter Serapis, near Naples in Italy. This was built near sea-level, and three of its columns are now standing, while the floor of the temple is beneath the water. At a height of twelve feet above their base, these columns begin to show the borings of a shell, the Litho-

domus, which bores in the stones on the shores of the Mediterranean. The borings on these columns continue through a distance of nine feet. They could have been made only while the columns were standing in water, and the reason for their absence in the lower twelve feet, is that the lower part of the columns were cased in mud. So, built on dry land, these columns sank twenty-one feet or more, and then were raised again to nearly this height. The additional fact that there is a second pavement beneath the upper one, shows that even while the Romans used the temple, the land was sinking, and a new floor had to be laid above the water level.

During the earthquake shock of 1891 in Japan, the ground rose perceptibly on one side of a fault plane, which was traceable at the surface over a distance of many miles (Fig. 219). During the earthquake shock of 1832, the land along the shore of Peru was raised to a height of three or four feet; and in 1835 a part of the coast of Chile was raised four or five feet. Along this western coast of South America, there is evidence of a much greater elevation in recent times.

On the other hand, the coast of New Jersey is known to be sinking at an average rate of about two feet a century. There is historic evidence of elevation along the coast of Hudson's Bay, an elevation which is proceeding at a variable rate, amounting in some places to

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several feet a century. In Scandinavia it has long been known that parts of the coast were rising, and other portions sinking. Shallow places became shallower, and on the same sections of the coast, rocks once submerged were found to come nearer the surface and finally rise above it. Along other parts of the coast, streets that had been built above sea-level were submerged. In order to test the amount of change, carefully located bench-marks were placed along the coast at the sea-level, and these are now found to be at different elevations. Therefore man is actually witnessing changes in land level in widely separated parts of the globe; but in most cases these are so slow that they are noticed only after long periods of time, and as the result of a carefully kept record.

Geological Evidence. — *Ocean Fossils on the Land.* Of geological evidences that there is a change in the relative level of land and sea, one of the best is the presence of sea-made sedimentary rocks, which occur on all parts of the land, even among the highest mountains. Not only are these strata found, but in them are many fossils of animals that lived and died in the sea, and were entombed in the growing rocks. (See Part III.) In some places, as for instance along the coast of the Gulf of Mexico, there are strata now above sea-level, in which are found fossils of species still living in the neighboring ocean waters. This shows that in some

cases the change in level has been comparatively recent; but in many of the rocks, the fossils are those of animals which long since became extinct.

Elevated Shore Lines. Along numerous coasts, also, there are distinct beaches and wave-cut cliffs, exactly like those now in process of formation at sea-level, but in these cases existing at an elevation of many feet above the present ocean surface. Such structures would not long stand the destructive action of denudation, and hence we conclude that these beaches were formed in fairly recent times, when the land was lower in relation to the sea. On the New England coast, particularly along the shores of Maine, and also further north on the coast of Nova Scotia, Labrador, and Baffin Land, there are beaches at an elevation of scores, or even hundreds of feet above the present sea-level. Cases of this kind are found on many coasts.

Evidence of Depression. Not only is elevation proved by geological evidence, but signs of depression are likewise found. In fact there may be proof of both upward and downward movements even on the same coast. Thus along the New England shore, there are many places where forest trees and peat bogs are found beneath low tide (Fig. 176). These must have grown above the level of the sea water.

Another evidence of the same movement is found in the bays, estuaries, harbors, and fjords of many coasts.

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Another evidence of the same movement is found in the bays, estuaries, harbors, and fjords of many coasts.

These are very often, indeed usually, river valleys which were formed above the water, but have been partially drowned by a change in the level of the land, allowing the water to enter the valleys. Such a coast as that of Maine (Plate 13), and indeed of all New England, furnishes abundant illustration of this class of evidence of land submergence. So also do the valleys of the St. Lawrence and the Hudson, as well as Delaware and Chesapeake bays on the eastern coast, while San Francisco harbor, and the irregular coast line of Washington and British Columbia on the western coast, and the irregular eastern boundary of northern Europe are due to the same cause.

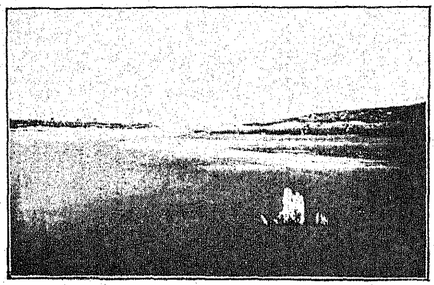


FIG. 176.

Trunk of a tree on a beach at Cape Ann, Mass. Standing where it grew, but now nearly at low tide mark.

Changes of Level in New England. On the New England coast there are registered a series of changes of level in recent geological times. We know well that the land was formerly much higher than at present, and that river valleys were then carved in the rocks. Then the New England region was submerged to a level below the present coast line; and at this period

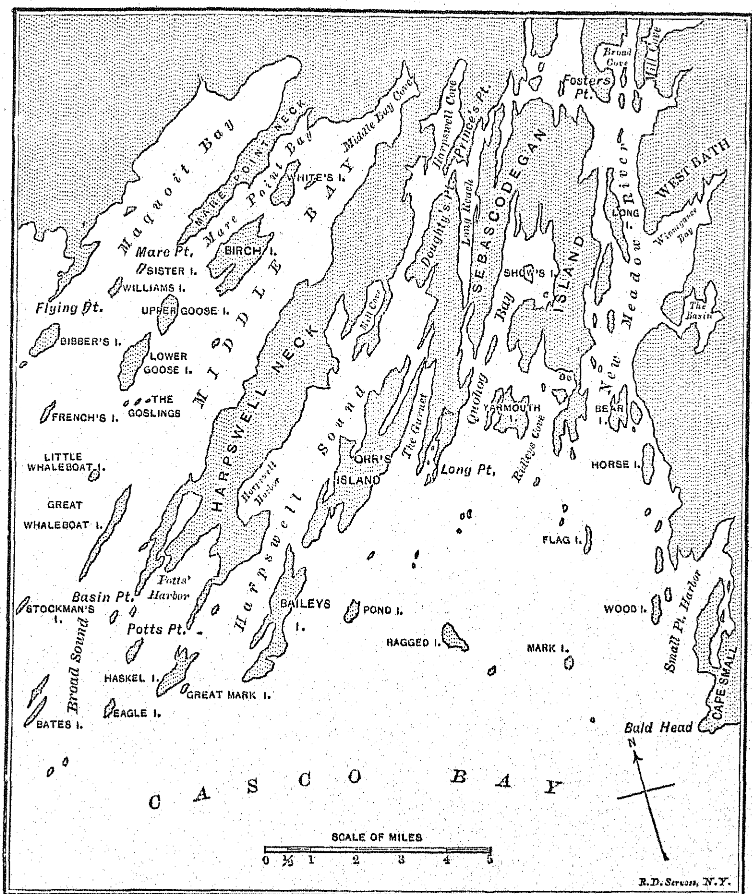


PLATE 13.

A part of the coast of Maine, showing irregular, depressed coasts.

of depression the beaches mentioned above were built. The land then rose to a height slightly greater than the present. At that time trees grew in places that have since been submerged (Fig. 176), while the sea-level was assuming its present position.

What changes occurred before this, cannot be so distinctly stated, for the further back we go in time, the less definite is the evidence. Nor can we tell satisfactorily the exact amount of the changes. Elevation brings beaches and other shore features *above* the water surface where they may be seen; but depression lowers them and hides some of the evidence from view.

In these various changes, one striking feature is their difference, even in neighboring places. It is not a uniform uplift or depression, but one somewhat irregular; and the greatest recent changes have been in the north. In some places, as in the northern countries, the average recent change has been one of depression; hence the irregular coasts of northern lands; but in other places, as on the coasts of Chile and Peru, the average movement has been a rising, and therefore the coast line is very regular.

The Changes a Result of Land Movement. — In the changes in level of the sea and land, it is often asked whether there has been an alteration in sea-level, or an actual movement of the land. In answering this question, we must first recognize the fact that there

are two quite different changes,—one of broad uplift or depression, which affects great areas, but works slowly, and which, because of its widespread effect, may be called *continental;* the other, a more local and more rapid movement associated with mountain action. The latter is certainly a movement of the land, for this has actually been seen to occur during earthquakes (p. 358). Moreover, as a result of this land movement, rocks are broken and folded, thus showing actual changes in the level of the crust.

Of the broader continental movements, there is also distinct evidence that in some cases at least, it is a positive change in the level of the land. This is true, for instance, of Sweden; for there is a rising in one part and a sinking in others, while on some of the neighboring coasts there is little if any change. In this region the water level would certainly not alter perceptibly, and yet with such different results at places near together. The movements in the interior, mentioned below, are also evidences of actual change in the land level.

It is probable that as a result of various causes there are slight variations in the sea-level; but these would affect large areas, and possibly, in the course of great periods of time, even produce notable results; yet certainly these are not of so much importance as the movements of the land itself. The sea is a mobile body, and any change would be widespread. It is also an

immense mass of water; and to disturb its level over the entire world, or even over a part of a hemisphere, would require changes in whose occurrence we have no reason to believe. Even the submergence of the American continent would not displace enough water in the ocean to account for some of the variations in level that have been recorded.

Variations of Level in the Interior. — It is to the seashore that we look for the best evidences of changes in level. A rise or fall of ten feet will produce effects here which are readily noticeable; but in the interior, away from the shore, a movement of ten times this amount might occur without being observed. There is nothing with which to compare the change, as there is near the seashore. Still in one or two places, we have good evidences of a change of level in the interior.

At one time, just at the close of the Glacial Period (p. 482), the Great Lakes were prevented from flowing out through the St. Lawrence, and were raised above their present level until they found an outlet over some low point in the rim of their basins. While at this level they built beaches, just as the present lakes are doing (Fig. 177). These were, of course, horizontal; but now they are tilted, and the tilting has raised the northern ends higher than the southern.

This is exactly what has been found on the seashore, and so we may feel certain that this recent uplift has

affected the whole northeastern part of our continent. An old lake in the valley of the Red River of the North also built shore lines which bear like witness. Hence from Minnesota and Manitoba to Labrador and New England, the land has been raised, and the north lifted higher than the south. In some places this uplift is still in progress.

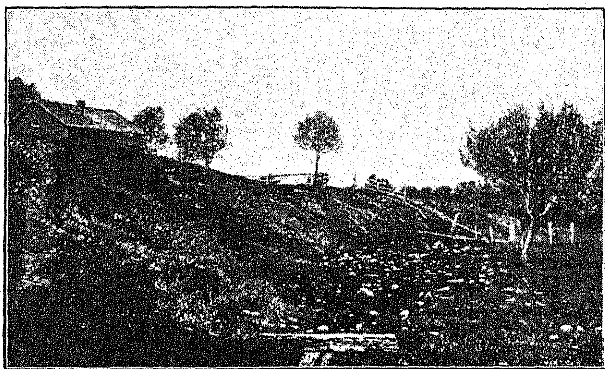


FIG. 177.

Ancient beach above present level of Lake Michigan.

This evidence from the lake shore lines of the interior is also proof of land movement; for of course changes in sea-level cannot account for the differences in level of these beaches. We may, therefore, conclude that the variation is usually one of the land, and that, while a change in the level of the sea is certainly possible, there is as yet no evidence that it has really caused any of the recorded elevations or depressions.

CHAPTER XVII

MOUNTAINS

Definition. — The term *mountain* is very loosely used. It commonly means any unusual elevation. In New England and central New York, elevations of from one to two thousand feet are called hills, but on the plains of Texas, a hill of a few hundred feet is called a mountain. Some are inclined to include under this term only those folded rocks which have been raised to an unusual elevation, and more or less carved by denudation. It would be difficult to restrict the term to this narrow meaning. In reality various features are included under the term mountain, and it is therefore best to analyze these land forms of unusual elevation, giving the different forms different names.

Nature of Mountains. — A folded mass, composed of anticlines and synclines, and formed by foldings which occurred at about the same time, is a *mountain range*. In the range there are *ridges* (Fig. 178 and Plate 14), which are either individual anticlines or, more com-

monly, the upturned edges of hard layers, which because of their hardness, stand above the general level. The ridges extend in a linear manner, having greater length than either height or width. So a real mountain range is made of various ridges.

In a range there are also areas, usually with bases more or less circular, which rise above the general

Fig. 178.

A mountain ridge, near Banf, on the Canadian Pacific.

level, forming *mountain peaks* (Figs. 103 and 179). These are commonly composed of some harder rock than the remainder of the mountain, and because of this, have resisted erosion more firmly than the rest. Or the peak may have been originally *built* to a greater height than the surrounding range, or it may be a divide area, where denudation has produced less effect.

Since its main characteristics are unusual elevation, and a more or less conical form, and since the present height and outline are largely due to the fact that the peak has better resisted the action of denudation than has the neighboring land, it seems fair to include among mountain peaks *any* unusual elevation, of a somewhat conical form, which has resisted denudation. So, therefore, the *buttes* or *hills of circumdenudation* (Fig. 180) (the hills which have been left because denudation has cut the rock material away from them on all sides) of the western plains, may properly be called mountain peaks. It is also customary to class volcanic cones as mountain peaks, but although this is certainly defensible, these are such typical geographic forms, that it is well to give them a separate name.

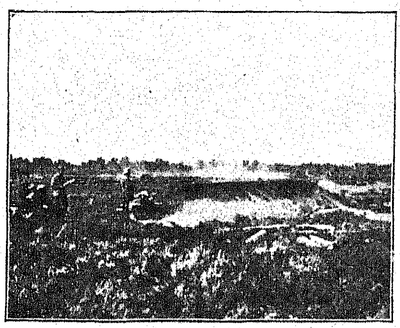


FIG. 179.
Mountain peaks in Teton Range, Wyoming.

Not only may individual peaks result from greater durability of certain classes of rocks, but great groups of peaks may be formed in the same way. For instance, this is particularly the case in the Catskills, which are not folded into anticlines and synclines, as

are the Appalachians, but are really a great plateau of durable sandstone and conglomerate rock, cut into rugged peaks with intervening deep valleys. Although somewhat disturbed, the rocks remain in a nearly horizontal position, and denudation has cut into these strata with less result than upon softer rocks on either side. Hence the Catskills stand above the surrounding country, just as folded or true mountains do. Their

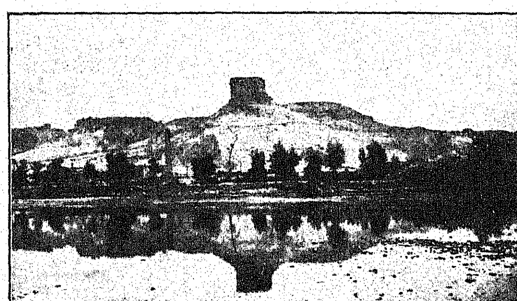


FIG. 180.
Green River Butte, Wyoming, a hill or peak of circumdenudation.

counterpart is found in the Cumberland Mountains of Tennessee, as well as in many other parts of the world.

While mountain peaks and ridges, grouped together, make a range, groups of ranges may combine into *systems* (Fig. 181). Thus in our western country, there are many ranges formed into the Rocky Mountain system, and in each range are numerous ridges and peaks. Several systems, with their enclosed plateaus

and valleys, form *cordilleras*. The Cordilleras of the West, which include the Rocky Mountains, the Basin Ranges, the Sierra Nevada, and Coast Ranges, and some other minor systems, are typical illustrations.

As mountains are exposed to denudation, if not growing, they are gradually worn down, being first cut into rough and rugged outlines, and later reduced to rounded

FIG. 181.

The Appalachian Mountain system and the bottom of the Atlantic near the eastern coast. (A reduction by photograph of a part of Ward's model.)

and gently sloping forms. As the wearing process continues, the harder rocks stand up as ridges or peaks; and so, to take two examples from opposite sides of the continent, we have the White Mountains of New Hampshire and Pike's Peak of Colorado, located where granitic masses have been better able to resist the effects of denudation than have the surrounding rocks.

When mountains are finally planed down by denudation, they may become mere hills, which, though not actually called mountains, are really mountain ranges in every particular, excepting that of great elevation, which to the average mind is the most important feature. Thus the ranges of hills and low mountains which extend from North Carolina through eastern Virginia, past Washington, through Maryland, Pennsylvania, and Delaware, thence across New Jersey, forming the Highlands of that

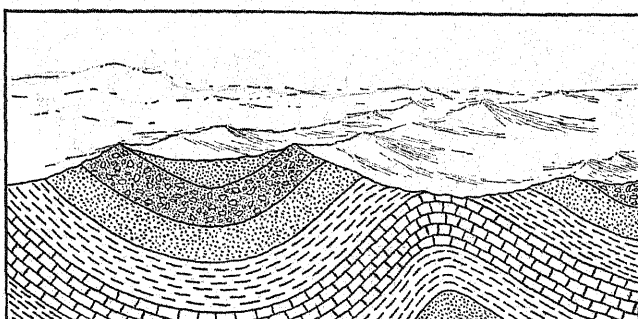


FIG. 182.

Section to show synclinal mountain and anticlinal valley.

state, and entering the southern part of New York, near New York City, are really mountains, though extremely old and much denuded, and worn down to their very roots. The same is true of the hills of Connecticut, Rhode Island, and Massachusetts. In these low and much-worn mountains, the more elevated parts are always those of the hard rocks, while most of the large valleys are situated in the layers of soft strata. In such cases, and in fact even before denudation has proceeded so far, anticlines which were originally mountains, are often worn down to valleys, and synclinal valleys are transformed to mountains (Fig. 182). Not only is this true here, but many of the Appalachian ranges are synclines.

Mountain Types. — Mountains may belong to either of two types, — those due to folding, or those formed by faulting. The faulted mountain block is very simple. On one side of a fault plane the strata are uplifted, and frequently upturned, so that the layers are left in an inclined position. These *fault-block mountains* (Figs. 183 and 184), which are common in the Great Basin of the West, sometimes pass gradually into mountains of monoclinal folds. The fault-block mountain has a steep face on the side of the fault, and a gentle slope on the side toward which the strata are dipping.

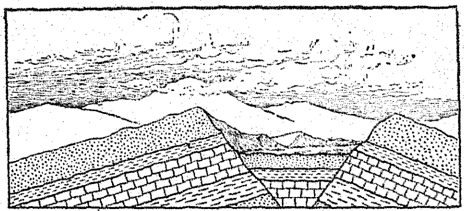


FIG. 183.
Diagram of fault-block mountain ridges.

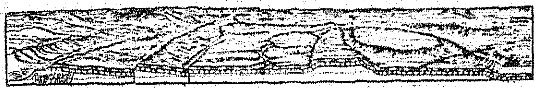


FIG. 184.
Monoclinal and fault-block mountains in plateau of Colorado River.

Of the folded mountains there are various types. The simplest is the *monoclinal mountain* (Fig. 184), in which, as in the fault-block type, there is a single ridge produced. Next in simplicity is the *anticlinal*

mountain (Fig. 185), which, when newly formed, consists of upfolded rocks, with the strata dipping away on both sides of the highest part, just as the sides of a roof dip from the ridge-pole. Here also, but a single ridge results from one fold; but as such mountains are cut down by denudation, they are often divided into two ridges (Fig. 186), where some hard layer in each limb of the anticline protrudes. As the fold dies out, these ridges unite by a loop (Plate 14). Still further denudation may bring the hard layers at the bottom of the syncline into sufficient relief to transfer the synclinal portion to a mountain, giving us what is then known as a *synclinal mountain* (Fig. 182).

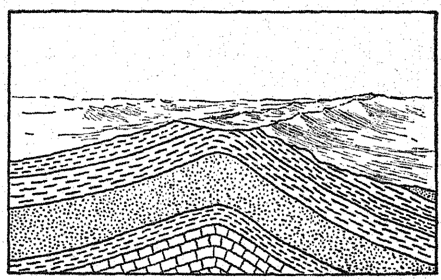


FIG. 185.
Anticlinal mountain ridge.

While the anticlinal fold may be symmetrical (Figs. 182, 185, and 186), with uniform dip on either side of the axis,[1] it is usually unsymmetrical (Figs. 187 and 188). This may increase to such an extreme of complexity, that the folds become actually overturned.

[1] The axis of a fold is the line passing through the centre, and extending in the direction of greatest length of folding.

PLATE 14.

Ridges and loops formed by etching out of hard strata in the Appalachian folds of Pennsylvania. (Photograph of a part of Harden's model.)

The accompanying diagrams (Figs. 187 and 188), showing the actual cross-sections of mountain ranges, will illustrate better than words some of the complex foldings of mountains.

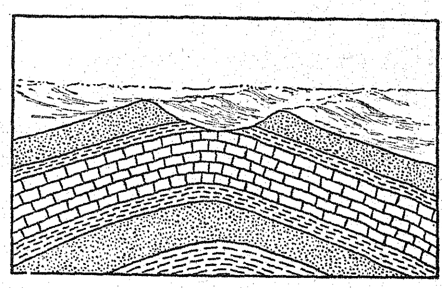


FIG. 186.
Two ridges produced by denudation of anticlinal ridge.

Besides these types of mountains, there are some in which the centre of a fold is made of a hard mass of rock, which, even after considerable denudation, stands up as a ridge extending in the axis of the fold. Again, the central mass of a mountain may be a lava intrusion (p. 349); and sometimes this has raised the layers into a dome, so that the strata dip away

FIG. 187.
Section through a part of the Appalachian Mountains, showing overthrust fault and unsymmetrical folds.

FIG. 188.
Section through a part of the Appalachians, showing faults and overturned folds.

in all directions from the centre.[1] Then the mountain fold may not produce a ridge, but rather, a more or less dome-shaped mass. These are numerous in some parts of Colorado and Utah, notably in the Henry Mountains of the latter state.

[1] Such a dip in all directions from the centre is known as the *quâ-quâversal* dip.

Thus there are many complexities of rock structure and mountain form; but the two main characteristics which are almost always present are: (1) disturbed rocks which have been more or less complexly moved from their original positions; and (2) the effect of denudation in planing down mountain tops, etching out the softer strata, and leaving the harder to stand above them, either as ridges or peaks.

Denudation is very active among mountains, for there is plenty of slope down which the water may run, and many mountain tops rise above the zone of the protection of vegetation, into a region where frost and winds readily attack the exposed rocks. Because the strata are of such different kinds, and so readily etched, the first effect of denudation is to produce an extremely uneven topography. It cannot be too plainly stated that folding is but one of several causes for the ruggedness of mountains.

Position of Mountains. — Mountains are present in nearly all parts of the world. So far as we know, they are more commonly found on the continents than in the oceans, but there are many mountain chains in the sea, and it is not unlikely that their apparent greater abundance on the land may be due, at least in part, to our imperfect knowledge of the ocean beds. Of these oceanic chains the Hawaiian Islands furnish a good illustration (Fig. 189). These extend approximately

N. 64° W. for a distance of about 1500 miles, rising above the surface in only a few places. There are also mountains which rise out of the ocean near the coasts of continents, as in the system which makes the Japanese archipelago. Then there are other ranges, such as the Andes, which are really part of the continent, but rise almost directly out of the sea. Many mountains, as

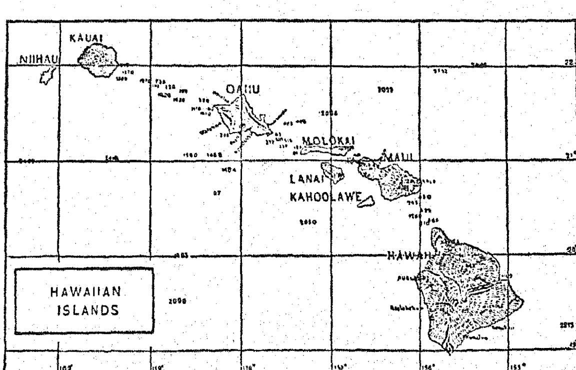


Fig. 189.

The Hawaiian Island chain, showing island peaks above the sea and the depth of the ocean near them (in fathoms).

for instance the Rockies and the Alps, occur in the interior of continents.

So it can hardly be said that mountains are confined to any particular locality of the earth. Still there are places, as the greater part of the Mississippi valley, between the Appalachians and the Rockies, where there appears to have never been any extensive moun-

tain growth, at least not north of Arkansas and Indian Territory.

There is much irregularity in the direction of mountain chains, although more of the extensive mountain ranges of the world extend north and south than east and west. The most remarkable instance of north and south extending chains is furnished by the ranges of North and South America, which form one nearly continuous mountain series from Alaska to Cape Horn.

On the continents there are usually two or three prominent sets of mountains. In North America there is an old mountainous highland in Canada, and two sets of mountains, the Appalachians and the western Cordilleras, which extend from northern to southern regions. These three axes are the skeletons about which the continent has been built. By their destruction, sediments have been produced and deposited in the neighboring seas, and from these accumulations, land masses have been made around the mountainous framework. A similar condition may be seen in South America and Africa, and it is from this that these continents have obtained their generally triangular shape; but the Australian and Eurasian continents are not so typical.

Taking as types the two great sets of mountains in this country, those of the east and west, we find that the mountain masses are really broad plateau uplifts, on which the real mountains exist as smaller wrinkles

(Figs. 190 and 191). The plateau pedestal of the Appalachians averages between two and three thousand feet above sea-level, that of the western mountains over a mile. Really then, the main feature in the mountain fold is the broad plateau, and the mountains,

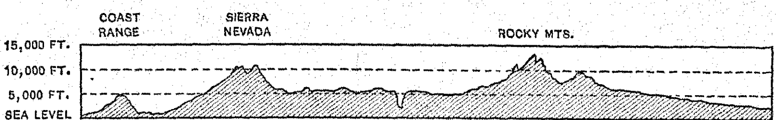


FIG. 190.

Diagrammatic section of the Cordilleras to show the importance of the plateau element. (Vertical greatly exaggerated.)

though attracting more attention, are inconsiderable sections of the uplift. Both are formed at the same time, but the rocks over the greater part of the area which is upfolded, remain nearly horizontal, though

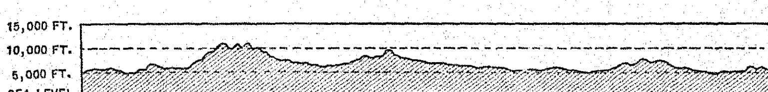


FIG. 191.

A section of a part of Fig. 190, showing on a larger scale the relative importance of the plateau and the mountain uplifts. (Vertical greatly exaggerated.)

locally, along certain narrow lines, they are broken by faults or raised and depressed by folds, some large and some small.

Permanence of Mountains. — These great lines of disturbance, the broad uplifted parts, seem to be permanent lines of weakness, along which the rocks fold again and again. In eastern United States there have been at least four or five periods of mountain

growth since the beginning of geological history; and disturbances of mountain folding have also frequently moved the rocks of the Far West, while in the Mississippi basin, between these regions, mountain folding has been nearly absent.

Where mountains were first uplifted in early ages, others have been formed at later times, whenever the proper conditions have come to pass; and on the other hand, where there was no folding in early times, there has been less chance of later mountain development. Continents seem also to have been places of general and frequent uplift, while ocean basins have been regions where, on the average, subsidence has been in progress. In other words, ocean basins have been permanently basins, and continents have been permanently places of greater uplift.

This theory of the permanence of mountains, ocean basins, and continents, does not mean that there are no exceptions, but that it appears to be a general law. Nor does it mean that a single mountain system has always been the site of elevation. While some mountains have been raised, and then worn down to their very roots without having suffered a second elevation, in some cases the same mountain chain has been uplifted more than once, or where this has not happened, other mountain chains have developed nearly parallel to them.

Slowness of Mountain Growth. — The forces that cause the elevation of mountains, apparently do not produce sudden or even rapid elevation. Mountains are now growing in various parts of the world, and their growth is no less rapid than the average mountain uplift. While, at certain periods, and in certain places, mountains may have been uplifted more rapidly than any that are now rising, such swift action does not seem to have been the rule in the past.

The Japanese Islands and the East Indies are instances of mountains that are even now growing; and yet plants and animals, and man himself, are able to dwell upon them as they rise, and man is scarcely aware of their growth. In some cases the uplift of mountains appears to have been so slow, that rivers have been able to maintain their courses across them as they rose; at least, this is the interpretation placed upon some rivers, such as the Green River of Utah, which cuts directly across the high Uintah Mountains.

One of the evidences of present mountain growth is found in the occurrence of earthquakes, which are often due to the slipping of the rocks as they break and move. A second evidence is the occurrence at the surface of actual breaks, or faults, on one side of which the land has been raised. Sometimes these movements of the rocks have been witnessed by man (pp. 294 and 358).

Of slow growth in the past, there is also evidence. While mountains have been rising, rivers have sometimes been dammed, and locally transformed into lakes, in which extensive deposits of sediment have been laid down. In some cases these have been upturned and folded into the mountains, the changes all occurring slowly, so that before the complete cycle was passed through, time enough had elapsed for the extinction of some kinds of life, and the development of new types. By this, the development of the mountains is known to have extended through ages. Moreover, the fact that rocks are folded, instead of shattered, indicates slow rather than rapid growth.

So gradual has been the uplift, that even while the elevation was in progress, denudation has been able to cut down the mountain tops, and thus little by little reduce the elevation. No mountains in the world rise to the height they would have reached if denudation had not been *relatively* important (Fig. 192). So far as known, the loftiest mountain peak on the globe is that of Mount Everest in the Himalayas, which rises to a height of about 29,000 feet above sea-level; and yet if the rocks which partially enwrap it were projected above, as they once extended, the elevation of this mountain would be vastly greater than at present. Everest has been raised in very recent times, and there is no reason for believing that it previously reached many thousands of feet higher into the air than at present; but rather, that as it rose, the layers that covered it were stripped off.

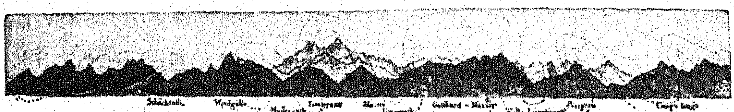


FIG. 192.

Section of a part of the high Alps. Dotted lines show the continuation of the folds if denudation had not reduced the mountains.

Intermittent Growth. — It has been said above, that many mountains have developed again and again, and that their growth has been not only slow but intermittent. Of this the evidence is conclusive, being furnished by the frequent *unconformities* (Fig. 193) among the mountains. A series of strata have been deposited in the sea, in a nearly horizontal position, and then folded, or faulted, and tilted into a mountain ridge. In the rocks are fossils which determine the age of the strata. (See pp. 395 and 397.)

This mountain is then worn by denudation for a while, and next is partially submerged in the sea, so that on its slopes other strata are deposited. In these are entombed fossils of a later age, while the unconformity represented by the denudation, marks a gap in the record of the animal life. Folding has again occurred, and both the first and second rocks have been uplifted and changed in position. Sometimes there are several

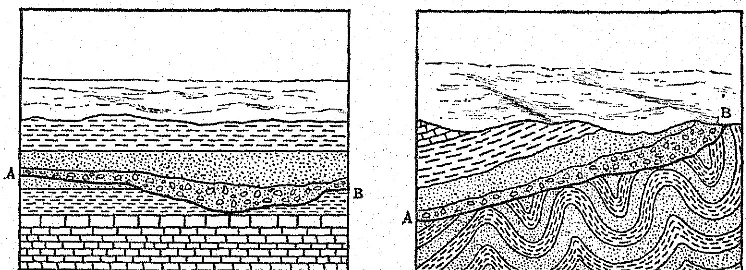


FIG. 193.

Two sections to show unconformities. The lines *AB* mark planes along which erosion occurred after the lower rocks were formed, and before the upper series were deposited.

such unconformities, the breaks being of different lengths. This kind of evidence is sufficiently common among mountains to make it certain that intermittent growth is a feature of their history.

Phenomena accompanying Mountain Growth. — Since slipping and faulting are common results of the uplift of rocks, mountain development is accompanied by jars which are known as earthquakes (p. 353). Again,

perhaps because of the fissures that reach deep into the earth, volcanoes are common among mountains, especially among those that are even now growing (p. 329). Because of the fissures which furnish the place for deposit, and because of the presence of heat and heated water, caused by volcanic action, and possibly by the slipping of rocks over one another, mineral veins (Chapter XX.) abound in mountainous regions.

The movement of the strata sometimes causes a crushing; and the presence of great pressure and heat, together with the action of heated waters, often cause rocks to be changed or metamorphosed during mountain development (p. 366). Hence metamorphism is a common accompaniment of mountain growth; and in the central parts of these folds, as well as deep down in the roots of mountains, which later are sometimes exposed by denudation, it is common to find the strata so altered and changed that their original condition is almost or even completely masked.

Cause of Mountain Growth. — *Phenomena to be Explained.* Although this subject has long been under consideration, geologists are far from being agreed upon the cause of mountains. It is quite generally believed that their growth has to do with the heated condition of the interior of the earth; but just in what way this causes mountain uplift, is still a subject for hypothesis. It is a question of great com-

plexity; for the facts are difficult of acquirement, and even when all available information is obtained, there still remains the necessity of assuming changes whose nature is not fully understood. So the physicists and geologists who have attacked this problem, have arrived at widely different results. In stating our present knowledge, it will serve us to pass in review, first of all, the phenomena to be explained.

There is first the fact that mountains rise in ridges, which in the majority of the larger ranges have a nearly north and south direction. Along or near these lines there have been uplifts, often repeated again and again, and these appear to have been slow and frequently intermittent.

For a long time before some of the ranges began to rise, there was a preliminary settling of the sea bottom, during which thick deposits of sediment were accumulated. In these cases, which are numerous, mountains have been made out of thick beds of sediment, long hidden under water. These sediments have been mostly, if not entirely, deposited near the shore line, so that mountains are often formed from *thick beds of shore-line sediment* which have gathered during a long-continued subsidence. In the Appalachians such conditions were present, these mountains being made out of beds whose thickness in some places became as great as 30,000 or 40,000 feet; and the same is true in many other chains.

Among mountains there is commonly evidence not merely of vertical, but also of horizontal movement. In the course of this there must, also, have been a resultant crushing of the materials, and sometimes an actual flow of the minerals of the rocks. It is as if the strata had been pushed by a horizontal stress from one side, just as we might crumple paper by pushing it against some immovable object. Applying this method of mountain formation, it has been possible to artificially make actual mountain folds by crumpling layers of wax, etc.; and among these folds, many of the phenomena of mountains have been very closely reproduced (Fig. 194). Evidence of horizontal movement is found in the presence of overturned folds, and of the reverse and overthrust faults (pp. 290–292), in some of which the rocks have been moved horizontally for thousands of feet.

While compression and horizontal movement are the common features, mountains exist in which the reverse appears to be true; and here the uplift seems to have been accompanied by a *stretching*, so that instead of reverse faults, the slipping has been such as to produce normal faults (p. 292). Such a condition is found in the Great Basin between the Sierra and the Rockies.

Contraction Theory. Any theory of mountains which is universally accepted, must explain all these phenomena; and it is because many believe that no

one of the theories does this, that there are so many explanations before us. In a book of this scope it will be impossible to do justice to the various theories of mountain development, and so we must be contented with the mere statement of the most prominent theory, and the reasons why to a very large number of geologists it seems the best hypothesis yet offered. It must be understood that there are arguments against it, that many do not accept it, and that it is merely a theory, or perhaps not more than a hypothesis.

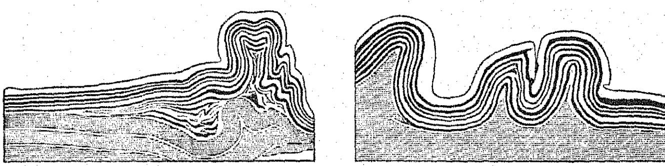


FIG. 194.

Imitation mountain folds produced artificially by subjecting layers of wax to a pressure from one side.

As originally stated, this contractional hypothesis was, that as the molten interior of the earth slowly cooled, it contracted, and the solid outer crust wrinkled in its constant attempt to surround the molten inner sphere, which was ever becoming smaller. With the general abandonment of the theory that the interior of the earth is molten, this hypothesis needed modification; but it is still essentially the same, if we merely substitute for the globe of molten rock, a highly heated, but solid interior. About this, the solid crust, which

does not contract, because it is already cold, is slowly folded as the hot core shrinks from loss of heat. It is very much like the wrinkling of the surface of an apple, which upon drying, loses vapor from the pulp, which hence contracts, causing the less watery skin to pucker (Fig. 195).

This theory appears to explain most of the phenomena of mountain folding. Granted that early in the history of the earth there were lines of weakness, due to one cause or another, these would again and again serve as places of folding as the outer rocks found it necessary to conform to the shrinking interior. At one time the area might be lowered, at another raised; for although the general level of the crust is always in process of lowering, locally, now and then, parts would be raised and folded higher than others.

FIG. 195.
Wrinkled surface of an apple caused by drying of interior.

This would account for the frequent evidences of subsidence, and for the occasional elevation along these and other lines, which would occur whenever, in the constant shrinkage, it became necessary for

some part to rise in order that the rest might settle. This rising would then have the appearance of a thrust from one side; for the necessity of sinking in one part would push up a neighboring portion. Naturally, this uplifted part would often be in the vicinity of the shore, for this line is near the place of weakness, where uplift is most frequent; that is, near a more ancient line of folding.

This theory also explains the slowness of folding; for of course, the contraction cannot be such as to produce rapid uplift. A local stretching, like that seen in the Great Basin, may merely be a broad upfold, which at this place is being stretched, while elsewhere, in other parts of the same fold, the rocks are being pushed horizontally.[1]

So it seems, that while objections are urged on more or less theoretical grounds, the contraction theory explains the main facts of mountain growth; and against it there can be fewer objections urged than against any other. Therefore, while it may not be the true explanation, it seems the most reasonable suggestion yet offered; and in this respect, compares favorably with many other attempts which man is making to account for the phenomena of nature.

[1] The crest or ridge of an anticline, or any upfold of this kind, is a place of stretching; the base of the fold, or the syncline is a place of pressing. This can be proved by pushing a piece of stiff wax-covered cardboard into anticlines and synclines.

The most serious objection urged against this theory is, that mere contraction is not sufficient to account for the known results; but there is grave cause for doubting the validity of this objection. The formation of mountains occurs in only a few comparatively small parts of the whole earth. In these places is concentrated the uplifting energy of all the rest of the sphere. Even then the elevation is very slow; and until better proof is brought to the contrary, we may fairly assume, as basis of the hypothesis, that the effect of contraction is sufficient.

Although it has seemed best to present this theory here to the exclusion of others, it should be admitted that contraction may be aided by various causes, such as have sometimes been suggested. It is particularly possible that the loss of gas from the earth may assist in the volume of contraction, just as the skin of a drying apple wrinkles whenever the water vapor passes from the pulp. Uplift may be greatly aided by the expansion of heated water which enters into the deep, lower parts of the earth, where the temperature is high. Even taken alone, each of these *may* be a cause for mountains; but more probably, if they act at all, they merely aid contraction, which appears to be the really important, and perhaps in many cases, the sole cause for mountain growth.

CHAPTER XVIII

VOLCANOES

Definition. — A volcano is essentially a vent to the surface, through which rises some kind of molten rock, which, upon accumulating, builds a conical peak (Fig. 196). This material may come up very slowly and quietly, or it may move with extreme violence. In either case a cone-shaped mountain is built around the vent, and this outlet, which is kept partially clear, forms a crater-shaped depression in the centre of the cone. Sometimes the material ejected is liquid lava, but very often it is volcanic ash, which represents lava blown into a porous mass by the expansion of the steam contained within it. At all times, steam is one of the important elements of the eruption.

Location. — As an almost universal statement, it may be said that volcanoes are situated in or near the sea (Fig. 197); and quite universally they are located among mountains which are now in process of growth. Very often they occur in lines, as if they were associated with fissures or faults. While volcanoes are fre-

quently found elsewhere, the greatest belt of active cones extends along the western side of the two Americas, thence across the northern portion of the Pacific, along the Aleutian Islands, and southwards through the Japanese Islands to the East Indies, where they abound. Thus the Pacific Ocean is almost completely enclosed within a line of volcanic cones.

FIG. 196.

Cone at summit of Vesuvius, built by eruption of ash.

While the number of volcanoes that are now active is not great, if we include under this term those peaks that have been built by volcanic action, but are now extinct or dormant, the number of cones is greatly increased. Thus at present there is not a volcanic cone in the United States, authentically proved to have been in eruption in this century; but in the great Cordilleran region of the West, there are many hundreds of cones, quite perfect in form, yet not really active volcanoes (Fig. 198). The same is true of many of the midoceanic islands, such as the Azores, St. Helena, etc. Probably, also, many of the coral islands of the midocean are existing upon the tops of submerged volcanic peaks.

While there are many regions in which volcanoes are now, or have recently been active in great numbers,

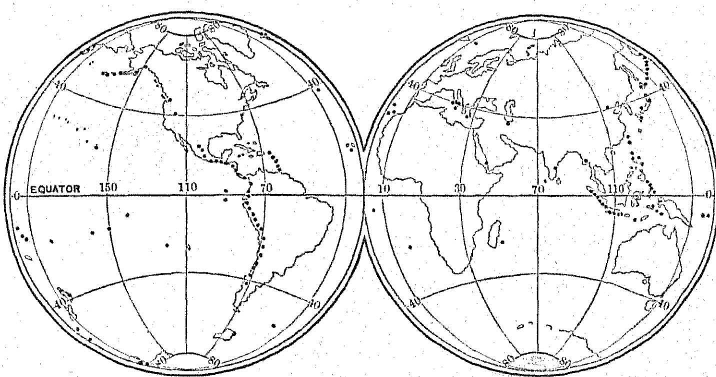


FIG. 197.

Diagrammatic sketch to show (by dots) distribution of volcanoes.

there are other areas, such as the main portion of the Mississippi valley, from the base of the Appalachians

FIG. 198.

Popocatepetl, Mexico, a volcano of perfect form which has not been in eruption this century, and is either dormant or extinct.

to the Rockies, in which there seems never to have been extensive volcanic action. Such places are those from which mountain growth has also been absent. Hence the association between volcanoes and mountains seems to be intimate. There is good reason for believing that in past ages, especially in those immediately preceding the present, volcanic action was more violent than now. This was the epoch in which the larger chains of mountains in the world were being formed; and hence, at this time, it is possible that mountain growth was more active than at present.

Products of Eruption. — Water, ash, and lava are the materials which are most abundantly ejected from volcanoes; but various kinds of sulphurous and other gases also burst from the vent. The aqueous portion of the eruption escapes as *steam*, rising in great volume and extending high into the air (Fig. 203). Much of it passes into the atmosphere as vapor, but considerable falls back to the earth in the form of rain. This may so deluge the side of the cone, that the water, rushing down the mountain side, takes up such quantities of loose ash as to become a flow of mud. These *mud flows* are very destructive, and some of the buried towns on the flanks of Mount Vesuvius have been covered by such a flow.

The *lava* usually escapes without great violence, and flows down the side of the cone, sometimes from the

crater, but very often from fissures in the side (Fig. 199). It emerges as a liquid rock, glowing brightly and flowing with rapidity (Fig. 200); but soon a crust forms

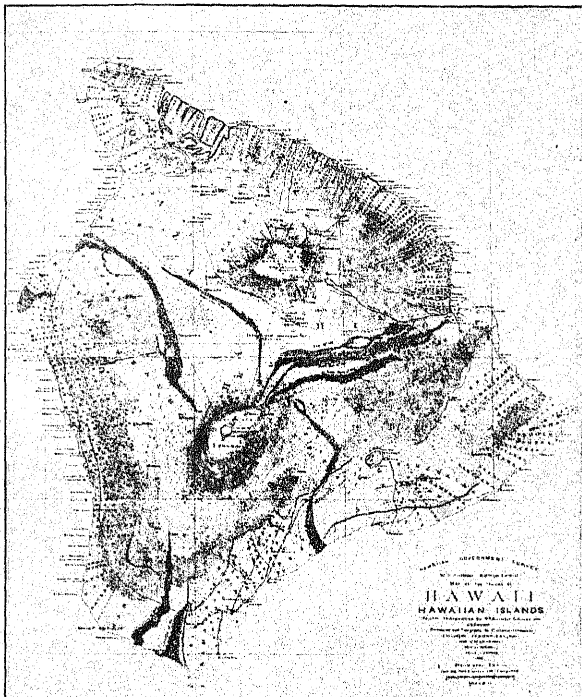


FIG. 199.

Mauna Loa in Hawaii, showing lava flows (the black portions) which started from fissures in the side of the cone.

upon its surface, and then its movement is retarded. As it proceeds on its course, the crust breaks, and sometimes this makes the lava flow so roughened by loose, angular

blocks, that travel upon it is impossible. Among the Hawaiian Islands this rough surfaced lava flow is

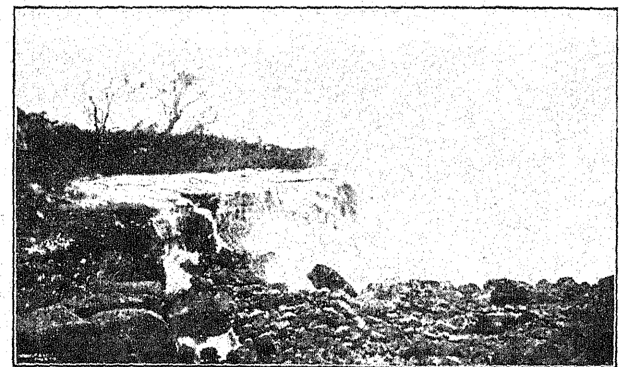


Fig. 200.
A lava flow in Hawaii.

called *aa* (Fig. 201), while the smooth surfaced lava, which has cooled without breaking, is called *pahoehoe* (Fig. 202). Both kinds may come from the same flow.

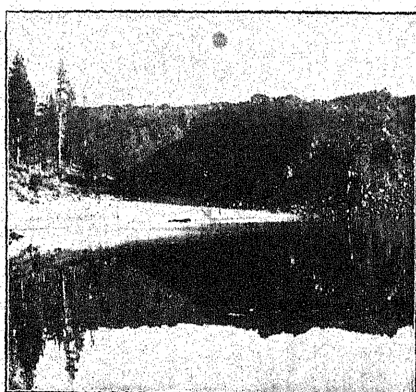


Fig. 201.
Rough *aa* surface at the end of a lava flow near Mt. Shasta.

Toward the last of the lava flow, movement is scarcely perceptible, and for weeks it proceeds forward very slowly. During this time one may

walk upon its surface, while the glowing lava may be seen at the bottom of the fissures, from which quantities of steam and other gases are rising. By expansion the water in the lava flow causes the rock to become porous and clinkery as it solidifies, quite like the slag from a

FIG. 202.
Pahoehoe surface of lava in the crater at Hawaii.

furnace (Figs. 14 and 15). Down below the surface, however, the lava becomes more dense, and when finally cooled the rock is entirely compact (Fig. 20).

Often when the eruption is violent, and indeed at other times, the lava is so blown to shreds by the rapid expansion of the heated water which it contains, that

instead of a lava flow, we have an eruption of true *rock ash*. This may be blown high into the air; and in the case of the smaller particles, even to elevations of several miles above the surface (Fig. 203). Much of it, particularly the heavier portion, falls back to the earth near the crater, the place of ejection. Since

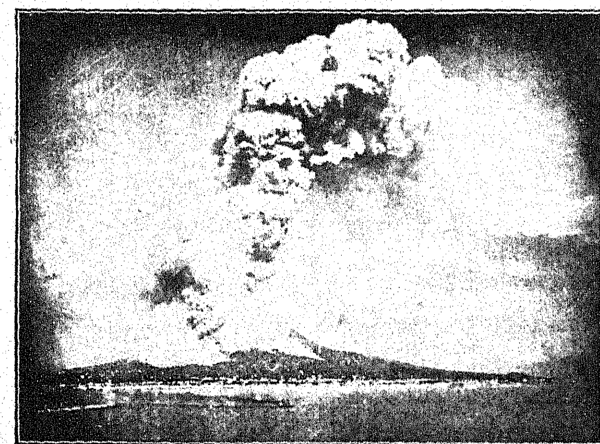


Fig. 203.

Photograph of eruption of Vesuvius in 1872, showing the steam and ash rising high in the air.

more falls here than at any other point, this gradual accumulation causes the mountain to rise in the form of a cone, built around the point of outlet; but much of the ash, particularly the light dust, drifts away in the air, falling miles from the place of ejection, possibly after being suspended in the air for months, or even years.

Since many volcanoes are in the sea, or along its shores, a great percentage of the ash from the eruption falls upon the ocean; and being light enough to float in water, much of it drifts away to distant regions. So in an ash eruption, only a part of the ejected material gathers near the cone, but in the lava outburst it all accumulates near the point of escape.

As a result of these differences, we find those cones that always erupt ash, very high, but relatively narrow at the base (Fig. 204). The cone is built up to a

FIG. 204.

Profile to show differences in area and steepness of ash (inner figure) and lava volcanoes (outer figure).

considerable elevation by the constant accumulation of ash near the point of ejection, but much of it passes away in the air or water. In a cone erupting lava, on the other hand, the liquid rock tends to flow away, like any rather pasty liquid, all staying in the neighborhood of the crater. So the mass which accumulates in such a case, is greater than that in an ash-erupting volcano which has emitted the same amount of material; but its height is less, because the lava tends to flow away from the place of ejection.

The lava flow may extend for a distance of twenty to forty miles, with a breadth of two or three miles, and

a depth of several hundred feet, or it may be only a tiny stream. Great lava flows occur in the Hawaiian Islands, and in Iceland. In the former the course is frequently interrupted by the sea.

In some parts of the world, there appear to have been great eruptions from fissures, without the accompanying formation of volcanic cones. In such places it seems as if the earth had cracked open, and lava had welled out from the fissure, overflow-

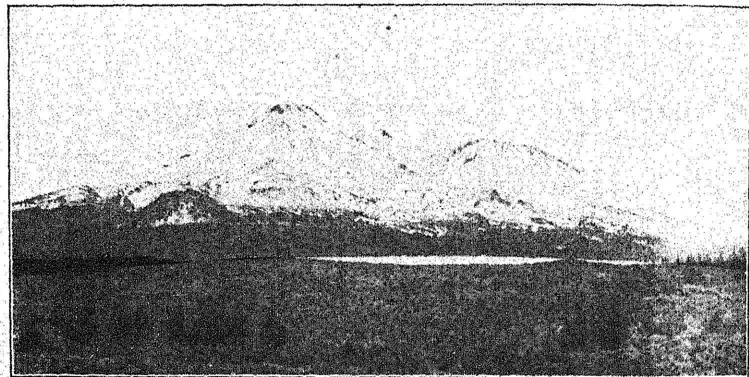


FIG. 205.

Mts. Shasta (on right) and Shastina, California. Two extinct volcanoes.

ing the country with an immense flood of liquid rock. In the plateau of the Deccan in India, and in the Snake River valley of Idaho, this was apparently the case. In the former place, the area covered by lava is fully 200,000 miles, and its depth in some places 6000 feet.

Nature of the Eruption. — The eruption of a volcano may take place from the crater, or it may begin from a fissure on the side of a cone, as is commonly the case

in the volcanoes of Hawaii (Fig. 199). Sometimes after a crater has ceased activity, an eruption may break forth on the sides of the cone; and then a new crater may be built, as in the case of Mount Shasta, where Shastina has grown on the flanks of Shasta in the form of a later and smaller cone (Fig. 205). Even a more recent cone has been formed near the base of Shasta, this being that of Lassen Peak.

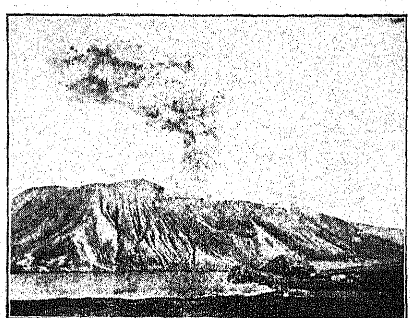


FIG. 206.
Vulcano, Lipari Islands, in eruption.

Some volcanoes are in almost constant eruption, as Vulcano (Fig. 206) and Stromboli in the Lipari Islands of the Mediterranean. The action is moderate, and vessels sail past the volcano without danger, even while the eruption is in progress. On the other hand, most volcanoes are in eruption only at periods several years apart. Often volcanoes which were supposed to be extinct have burst forth again. Krakatoa, in the Straits of Sunda, after being quiet for about a century, became suddenly active, in the fall of 1883. This was the most violent volcanic outbreak that has occurred in recent times (p. 343).

Similarly, Vesuvius, before the year 79 A.D., had not been in activity from the time the Italian peninsula was first visited. After this rest of many centuries, the cone of Monte Somma, as the volcano at that time was called, was blown open by a terrific explosion; and since that time, Vesuvius has been built on the ruins of Monte Somma, a part of which may still be seen as a half-collar on the rear side of Vesuvius. Ever since that famous catastrophe, this volcano has been active, although its activity has been very much greater and more constant since 1631 than between that time and the notable eruption of 79 A.D.

Another type of volcano is that of Kilauea (and also Mauna Loa) in the Hawaiian Islands, which breaks out about every eight or nine years, always with an extensive flow of lava, coming not from the crater, but from the sides of the mountain (Fig. 199). The amount of lava thus poured out is immense. There is no ash, and the violence of the action is not great. Between the eruptions, lava may be seen standing in the immense crater, which is occupied by a great lake of molten rock (Fig. 207). When the eruption takes place, the surface of this lava well sinks, for the molten rock contained in the crater is then escaping through a fissure broken in the side of the cone.

Among volcanoes there are also great differences in

the material erupted. Some always send out lava, as does Kilauea; some, like many of the American volcanoes, south of the United States, and the Japanese volcanoes, nearly always erupt ash; and others erupt both ash and lava, now one and now the other. This latter type is illustrated by the majority of volcanoes in the world, notably Vesuvius and Etna. Since lava

FIG. 207.

The crater of Kilauea, showing the great lava lake.

cones are broad, while ash cones are narrow and steep, we have every intermediate form between the very broad mountains of Hawaii and the wonderfully steep but symmetrical Fusijama in Japan.

There is also a difference in the chemical composition of the lavas. Some volcanoes always erupt one kind of rock. For instance, the Hawaiian volcanoes always

erupt basalt, while from some of the Mexican cones acidic rhyolite or trachyte lavas are always erupted. On the other hand, some volcanoes erupt one kind at one period and another later, as in the case of Vesuvius.

Reasons for Differences in Eruptions. — The reasons for these differences can be partly stated. Those volcanoes which always erupt one kind of lava, evidently reach down to the same reservoir at all times; but those that vary in the nature of the rock erupted, must tap different reservoirs at different times, for in various parts of the earth the chemical composition of the molten rock must certainly vary.

The explanation of the other variable features of eruption, is to be traced to the steam which is the immediate cause of outbreak. If the melted rock is very liquid, like the basaltic lava of Kilauea, the steam readily escapes; but if it is more pasty, the steam is partly prevented from escaping. When the steam does pass through the pasty lava, it necessarily blows holes in some of the rock, just as a thick fluid during boiling is spattered by the bubbles of rising steam. If a crust of lava has formed in the crater, the steam may become so confined, that when it gathers power enough to escape, it blows away the rock, causing a violent eruption.

It is a fact that the most tremendous outbursts take place after long periods of quiet. This evidently means,

that for some reason, the power of the steam was not sufficient to keep the tube or fissure clear; and therefore in this vent, the lava, which has cooled from liquid to consolidated rock, thus forms a plug in the tube. When this is accomplished, the volcano becomes dormant; but it may be gathering force for a terrible eruption. When the accumulated energy of the steam becomes great enough, either the plug is blown out, or the cone split and partly thrown into the air.

These are the most terrible of eruptions, and the experience of Vesuvius warns us against believing any volcano to be actually extinct so long as the cone shape lasts. It need not surprise us at any time to hear of violent eruptions in some of the so-called extinct volcanoes of the Far West, which are possibly only dormant. Still in process of time, the supply of energy so far fails as to become inadequate to cause further eruption, and then the cone does become actually and permanently extinct.

Eruption of Krakatoa. — The most notable eruption that has been carefully studied, is that of Krakatoa in the Straits of Sunda. In the spring of 1883, after a long period of quiet, this cone began to show signs of activity, and from it proceeded numerous earthquakes. These evidences of awakening energy culminated in the latter part of August, 1883, in an outbreak, which blew one-half of the island into the air (Fig. 208). A prodigious mass of ash and dust was hurled upward, apparently reaching elevations as great as fifteen miles above the level of

the sea. Here the finer portions floated about in the upper air currents, passing entirely around the earth, and causing brilliant sunsets in both Europe and America. To a distance of 150 miles from the eruption, the day was darkened.

The division of the volcano into two parts, left water on the site of half the island; and this change produced such a disturbance in the water, that a great ocean earthquake wave was formed, which, rushing upon the neighboring coast, and flooding it to a height fully 100 feet above the average sea-level, caused an appalling loss of life. This wave extended as far as the coasts

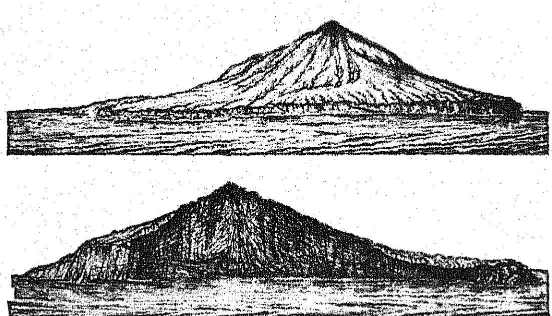


FIG. 208.

The island of Krakatoa, seen from two sides, after the eruption.

of America, Africa, and Australia, having passed over a distance of more that 5000 miles. At these distant points the wave was low, but still was a disturbance of the water, which could be detected by tide gauges.

Some of the ash, upon falling back on the cone, covered the entire surface to such a depth that all forms of life were utterly exterminated, so that a new vegetation has been obliged to develop upon the island. Vast quantities of the ash also fell upon the neighboring sea, and floated about in such masses that for weeks navigation near the volcano was difficult. This ash, drifting on the ocean surface, either slowly disintegrated or became water-

logged, and settled over the bottom of the Pacific, thus making a distinct contribution to the sediment of the ocean floor.

There have been many eruptions of great violence, but most volcanic outbreaks are moderate indeed in comparison with this. Still, even the mildest eruption is a most impressive evidence of the great power that exists within the earth, and is able to cause the ejection of liquid rock from points miles below the surface.

Effects of Volcanoes.—One of the most momentous effects of volcanic action is the destruction of life. Such loss is due not merely to the ash and lava, but also to the water wave that is often started by the eruption, and to the earthquake shocks which result. By these the lives of plants, of animals, and of man himself are endangered. Sometimes animals and plants are entirely exterminated for distances of many miles from the centre of eruption, and the earthquake shock and water wave often carry the disaster still further. By this destruction of life, fossils of animals and plants are frequently buried and preserved beneath the ash or lava, and thus is maintained a record of some of the organisms then living. In the case of Pompeii and Herculaneum, which were buried during the eruption of Vesuvius in 79 A.D., cities and works of man have been perfectly preserved (Fig. 209).

Flows of lava extend over the land and sometimes pour into the sea, where they are perhaps covered by later sedimentary rocks. Then we have *lava sheets* included between the members of a series of sedimen-

tary strata. This is the case in some of the trap hills of the Connecticut valley. Not only is material added to the earth's surface in the form of lava flows, but also in the condition of volcanic ash; and since much of this falls into the sea, this source becomes an important one for the sediments forming in the ocean. Another effect of geological importance is the building of the cone, which forms a distinct and impressive feature of the land.

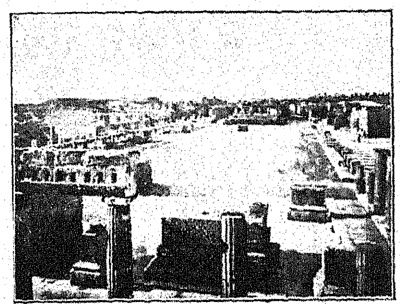


FIG. 209.

Pompeii with Vesuvius in the background. This town was buried by the eruption of 79 A.D., and is now being excavated.

Since the material that comes out at the crater must reach the surface through a conduit or tube, and since this must be filled when the volcano last erupts, in the centre of every extinct volcano there is a solidified plug of lava. This is harder than the ash and the lava flows that have built the cone, and when it is reached by denudation, remains as an elevated portion, mainly because of its greater resistance. These steeply rising hills are called *volcanic necks* or *plugs* (Fig. 215).

When a volcanic eruption breaks a fissure through a cone, as is so frequently done in the volcanoes of the

Hawaiian Islands, the lava that cools in this fissure forms a *dyke* (Fig. 210). When the crater is plugged, the attempt of the lava to reach the surface often breaks the strata, and thus also dykes are intruded into fissures, giving temporary relief to the strain that

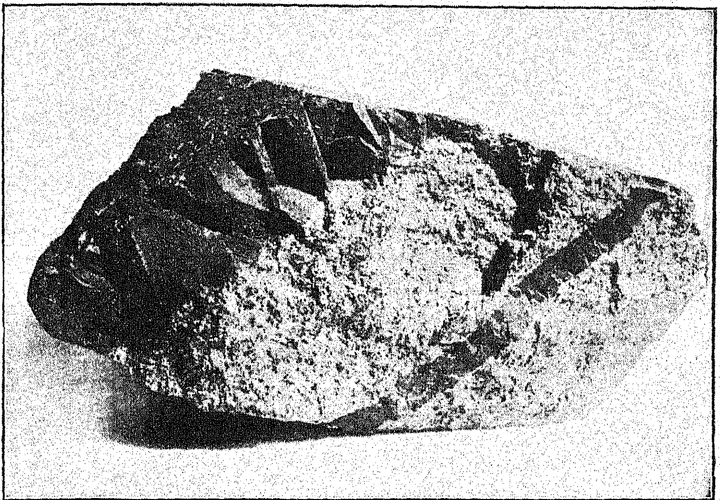


FIG. 210.
Dykes of black diabase crossing lighter granite.

is forcing the lava upward. Near every volcano, deep down below the surface, there are numerous dykes formed, each representing either a successful or an ineffectual effort on the part of the lava to escape. Such intruded dykes are found far from volcanoes, where denudation has laid bare the formerly buried strata.

Sometimes these dykes spread out between the layers of sedimentary rocks, forming *intruded sheets* (Fig. 211), like the Palisades of the Hudson, and East and West Rock of New Haven, Connecticut. Again they break

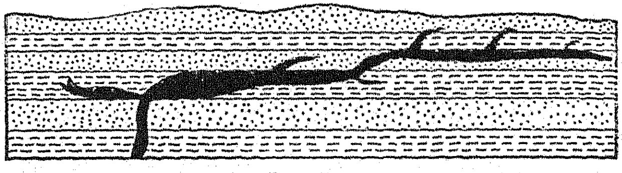


FIG. 211.
Diagram to illustrate intruded sheet.

great, irregular cavities deep in the earth and fill them with lava, which upon cooling, forms a *bosse* of plutonic rock, like granite (Fig. 212).

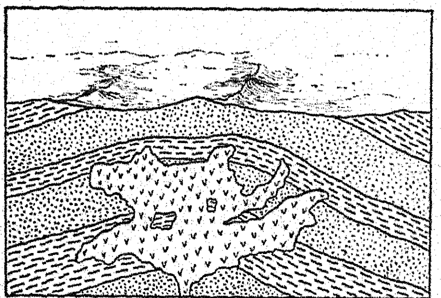


FIG. 212.
Diagram to illustrate bosse of intruded rock *B*.

Sometimes intruded lavas bend the layers of rock above them into the form of a dome, filling the space with lava (Fig. 213). These are known as *laccolites* (or laccoliths), and are really volcanic eruptions that did not quite reach the surface, but elevated the rocks instead of breaking them. They are found among the mountains of Colorado and in the Henry Mountains of Utah.

The intrusion of these great masses of lava into the earth, adds heat to parts of the cool crust. As a result of this the rocks are often baked and metamorphosed by contact with the intrusion; and as steam reaches out into the surrounding strata, many interesting changes are caused. Many hot springs and mineral veins no doubt owe their origin to these supplies of intruded heat. A great mass of lava, blanketed by cold rocks, which are poor conductors of heat, will take many centuries, and probably many thousands of years to cool. During all this time the neighboring strata are heated, and water with very high temperature is constantly passing through them, so that profound changes may result before the intruded rock cools.

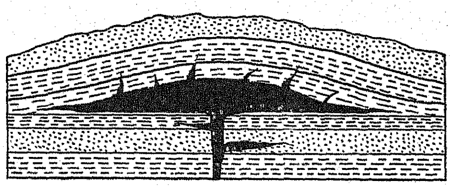


FIG. 213.
Diagram to illustrate laccolite.

Finally, volcanic eruptions are frequently responsible for earthquake shocks and earthquake water waves in the ocean. Even the ineffectual attempts of lava to reach the surface, when it forms dykes, etc., also produce earthquakes; and hence, in this indirect way, volcanoes do much destruction on the earth. A volcanic eruption is usually preceded and accompanied by such shocks.

History of the Volcanic Cone. — Commencing with a single eruption, during which a cone was built about the point of ejection, the volcano grows with each successive outbreak (Fig. 214). If in the sea, it will grow rapidly until the surface is reached; for here there is nothing to remove the erupted material. Such a cone will be steep, because there is no strong action which would tend to distribute the materials.

On the land, however, as the volcano grows upward, denudation at the same time attacks it, spreading some of the materials about, and thus lowering the level of the cone. Not only is the height reduced and the breadth increased, but the surface is carved and gullied (Fig. 198). Also, if ash is erupted, much of it will be carried away in the air. So long as eruptions are frequent, the additions from within will exceed this tendency to

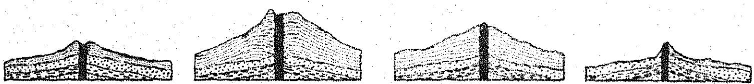


FIG. 214.

Diagram to illustrate life history of a volcano.

destruction, and the cone will grow, although temporarily it may be partially destroyed by a violent eruption (Fig. 208).

However, when eruption ceases, and there are therefore no further additions from below the surface, denudation acts in excess (Fig. 205), and the cone becomes more and more gullied, and lower and lower, finally losing all semblance to the volcanic cone; and as a last stage, with the cone gone, the neck or plug may stand up as a peak (Fig. 215), while the dykes of hard lava rock project above the surface. The volcano becomes extinct, then loses form and size, and finally is entirely destroyed. Among the Cordilleras of the west there are illustrations of every gradation between the young cone, fresh and perfect in outline, as if formed yesterday, and the entirely extinct and nearly destroyed volcano, whose form tells us nothing concerning its history.

The Cause of Volcanoes. — The immediate cause of volcanic eruption is undoubtedly the explosive action of steam, so that the volcanic outbreak is like a great boiler explosion; but the question of the origin of the heat is less easily answered. As in mountains, there can be little doubt that the heat is more or less directly associated with the high temperature of the earth's

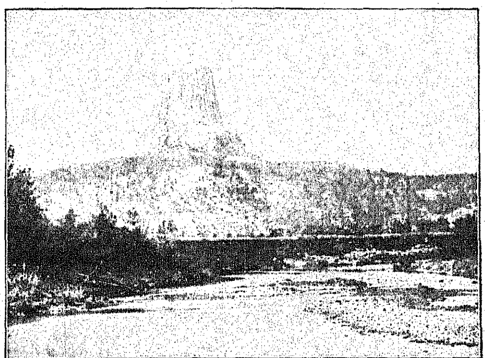


FIG. 215.

Mato Tepee, a volcanic neck rising 1100 feet above the river.

interior. The theory that explains mountains will likewise explain the original source of volcanic energy. Contraction of the earth, forming mountains, produces fissures in the rocks; and through these the lava rises, building volcanic cones. Perhaps the pressing action of folding strata causes the rise of liquid rock near enough to the surface to be expelled by steam.

Some have suggested that the rocks in the roots

of mountains are melted by the folding of the strata, this folding being powerful enough to produce sufficient heat for actual liquefaction. Then this molten lava is squeezed out through fissures and forced up to the surface by steam. Again, it has been thought that water has passed down to regions of melted rock, and by its expansion, has furnished sufficient energy for the eruption. Another theory suggests that chemical changes in the rock have caused melting and eruption.

Hence we see that there are many questions concerning the origin of volcanoes, which at present cannot be answered, for the problem deals with conditions so far from the surface that their cause and action are but matters of speculation. Still, steam produces the eruption, and mountains open fissures through which the lava can rise. What produces the lava, steam, and the mountains, are the unanswerable questions. If we suppose that the great heat is originated by the mountains, we appeal to a cause whose nature is not understood. So since the answer is not at hand, it is necessary to leave the question indefinite.

If the jar started from a point, the wave would move outward in all directions, maintaining a spherical form. In fact, this is never the case in nature, for the wave usually starts from a plane, and passes through rocks of varying density, so that from point to point it is liable to change its rate of progression.

Assuming a wave to be nearly spherical, it passes through the rocks just as a jar would move through a piece of steel, suspended and heavily struck (Fig. 216). The place from which the wave starts, is the *focus* of the earthquake, and a point directly above this, where the wave first reaches the surface, is called the *epicentrum*. This is the place of greatest violence; and if we have the theoretical conditions, the violence gradually and uniformly decreases in all directions outward from this point. Also, starting from the epicentrum as the centre, and describing a circle with any radius, this will pass through points at which the shock simultaneously reaches the surface. This circle is the section of a spherical wave cut by the surface of the earth.

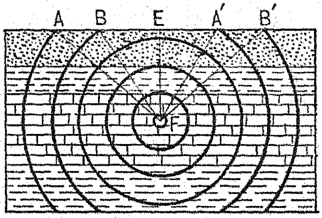


Fig. 216.

Diagram to illustrate progression of earthquake wave, from focus (F). Epicentrum E; isoseismals AB' and BA'. The shock reaches B and A' at exactly the same time.

In reality, this ideal condition is not exactly repro-

duced in nature. The wave passes through some rocks more rapidly than through others, and hence the circular lines[1] are distorted (Fig. 217). The violence also varies greatly with the nature of the rock; for some strata transmit the wave readily, and others retard it. From these and other causes[2] the shock becomes a complex movement. Starting no doubt as a jar, composed of a few waves, it becomes so complex that the earth vibrates with them; and even after the actual violence of the shock is past, it seems as if the rocks were being shaken with great force and rapidity.

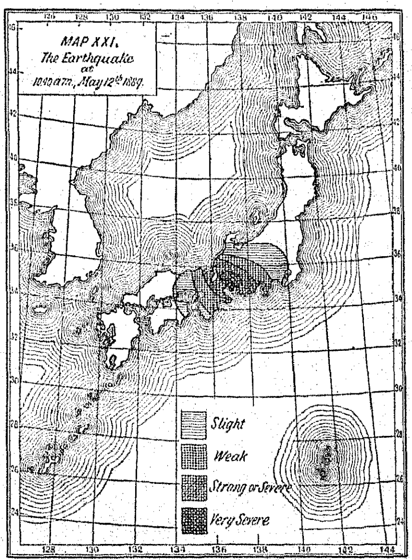


FIG. 217.

Japanese earthquake, showing distorted isoseismals and decrease in intensity of shock from epicentrum outwards.

Sometimes during an earthquake there are frequent small shocks for days, then the violent jarring and

[1] Called isoseismals, or lines along which the earthquake shock reaches the surface at exactly the same time (Fig. 216).

[2] Chiefly the reflection of the waves in passing from one rock to another, and the wave interference caused by differences in texture.

shaking, which may last for several minutes, and after this a series of lesser shocks, extending over several days, or even weeks, before the earth finally settles down to quiet. At times the earth has been in a state of tremor for months; on other occasions the shock is merely one violent shaking, hardly preceded or followed by minor movements. Even then the horizontal and vertical motion of the ground is but slight.

Fortunately the area of great violence is usually small in extent, being confined to a tract not far from the epicentrum; but the jar may be perceptible to people hundreds of miles away, and by instruments it may be measured at much greater distances. The Charleston earthquake of 1886, with the epicentrum near Charleston, South Carolina, was measured at Louisiana, Missouri, along the Great Lakes, and in Massachusetts. The earthquake which destroyed Lisbon, Portugal, in the year 1755, was felt as far as this country on the one side, and Africa on the other. The rate of motion of the earthquake wave is variously estimated from two or three hundred feet to several miles a second.

Effects of Earthquakes. — One of the most striking effects of earthquake shocks is that upon life. Loose and unstable objects are thrown down, and thus much destruction is caused. When the epicentrum is near a city, the greatest disaster follows from falling buildings (Fig. 218), which after being thrown down, often take fire. Entire cities have been almost completely destroyed, and with them a large percentage of the inhabitants. In steeply sloping regions, the shaking of the

ground dislodges rocks and even starts avalanches, thus furnishing an aid to weathering. Sometimes the shocks dam good-sized rivers by throwing down masses of earth.

One of the most important effects is the production of an earthquake water wave, which is formed when the epicentrum is in or near the sea. This rushes with

FIG. 218.

Destruction of property during Japanese earthquake of 1891.

fury upon the neighboring coasts, overwhelming everything in its path, and sometimes reaching 100 feet above the general water level. Fortunately this is destructive only on the neighboring shores; but as a measurable wave of water, it may pass half way around the earth. Such waves, starting on the Asiatic coasts, have been measured on our western coast.

Accompanying the shock there is often a change in the level of the land, either an uplift or a depression; and in such cases, fault-scarps, or cliffs are actually formed. This was particularly noticeable in the Japanese earthquake of 1891, in which a fault appeared at the surface of the earth for many miles (Figs. 170 and 219). In other cases there have been irregular depressions in which lakes have gathered, as happened in the Mississippi valley during the violent earthquakes which devastated that region in the years 1811–1812. However, in many cases, these are not caused *by* the earthquake, but are rather *accompanying phenomena*, which perhaps represent the cause of the shock.

Cause of Earthquakes. — In considering the cause of these jarrings of the earth, it is well to look first at the regions in which they are likely to occur. Places where earthquake shocks are frequent and violent, are usually either among mountains of recent or present growth, or else in the neighborhood of volcanoes. Yet shocks are apparently possible in any part of the earth.

In this country, during the present century, we have had two shocks of some violence east of the Rocky Mountains, one at Charleston, South Carolina, the other in the Arkansas region of the Mississippi valley. During the same time, in the much smaller area of Japan, there have been more than a score of shocks, each equalling or exceeding our own in violence. Among the Cordilleras, also, there have been numerous jarrings of the earth, some assuming considerable intensity. Another noteworthy fact is that shocks appear to start from a plane, not from a point. It is significant, too,

that sometimes a series of shocks occurs in the same place year after year.

There are several causes which may produce these jars of the rocks from which earthquake shocks originate, each cause probably accounting for some. The falling in of a cavern will effect a jar in the strata, and a landslip will do the same. In England some of the smaller earthquake movements have so originated. Struggles of gas, particularly steam, imprisoned within the rocks, will cause jarrings which are true earthquakes; near volcanoes, this cause of shocks is constantly present and frequently active.

A fourth way in which earthquake shocks may be produced is by the breaking or faulting of the rocks. As they snap and move, they cause a jar; and each slip starts a shock of great or small intensity. Such a movement would be along a plane, and the dislocation from which the jar originated might even be apparent at the surface (Figs. 170 and 219). From the constant slipping of the rocks along such a plane, innumerable shocks of more or less violence might originate, keeping the earth thereabout in a constant state of unrest; but only during a distinct and decided movement would a really severe earthquake shock occur. During the folding of mountains these faults are common; and hence, while mountains are growing, earthquakes must of necessity be frequent.

The fifth cause for earthquakes is the attempt of lava to escape. It may succeed in rending the cone, and thus bring about conditions favorable for violent eruption. In such cases the earthquake is a part of the eruption, as was so well illustrated at Krakatoa

FIG. 219.

Cracking of the ground along the fault-plane, revealed during the Japanese earthquake of 1891. The shock was caused by this faulting.

(p. 343). Or the attempt of the lava to reach the surface may be only partially effective, so that the dyke, sheet, or intruded mass may be thrust violently into a fissure broken in the earth. This would also cause an earthquake; and from such a source, numerous shocks might spring. As the earth ruptures, and the

lava flows into the crevices, each break reaches the surface as a shock. It is no doubt for this reason that volcanic eruptions are preceded and accompanied by earthquakes, each ineffectual attempt of the lava to escape at the surface sending a jar through the rocks.

The last three causes probably explain the majority of the earthquakes of the world, and nearly all those of serious consequence. This being true, earthquake shocks will naturally be most common near volcanoes and among growing mountains; but any one of these causes may appear at any time in any part of the crust, although not likely to exist far away from their common source. For great earthquakes there may be other causes, though none as yet appear. For minute jarrings, even the passing of a heavily loaded wagon is a sufficient cause.

From what has been said, it will be seen that most, if not all, great earthquakes are merely another expression of the influence of the internal heat of the earth, possibly exerted through the action of contraction. They are certainly a result of mountain folding; for both faulting and the intrusion of lava are commonly associated with this. Hence the source of the immediate causes for the majority of great earthquakes is mountain formation; and they may therefore be considered among the secondary phenomena of mountain growth.

Geysers and Hot Springs

Hot Springs. — In many regions of the world, warm or hot water rises to the surface from hot springs. These, though not confined to such localities, are most common near volcanoes, or in regions where these have recently been active. Some apparently reach deep into the earth along fissures (Fig. 72), while others originate near the surface. They bring up in solution great quantities of carbonate of lime, silica, and other mineral substances. So they are engaged in an important chemical work deep in the earth, and at the surface are depositing a portion of their product (Figs. 33, 34, and 221). Many deposits of ore have been formed by the action of heated water, and it is probable that down in the tubes of numerous hot springs, deposits of valuable minerals are even now being made.

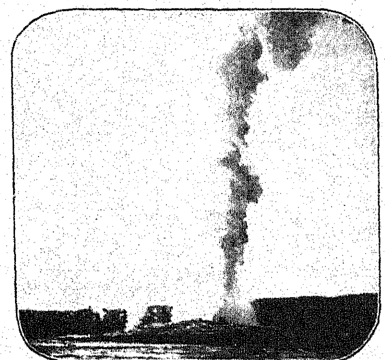


Fig. 220.

The Giant Geyser, Yellowstone Park, in eruption.

Geysers. — In several widely separated regions, but chiefly in New Zealand, Iceland, and the Yellowstone

Park of Wyoming, some of the hot springs have the habit of intermittent eruption; they are then called geysers (Fig. 220). These are crater-like springs of hot water, often surrounded by a cone of silicious sinter of their own building (Fig. 221). Most of the time the geysers are mere springs, but at certain intervals they eject water and steam high into the air.

After an interval, sometimes of a few minutes or hours, and again years, these geysers break forth, and from their outlet issues a column of steam, rising sometimes to a height of one or two hundred feet. Before the eruption commences, the water boils; and at all times water with a temperature nearly at the boiling-point is present in the spring. That these geysers are only a special kind of hot spring, is shown by the fact that in the Yellowstone Park, a geyser (the Artemesia) has developed from a hot spring since the Park was set aside for the public.

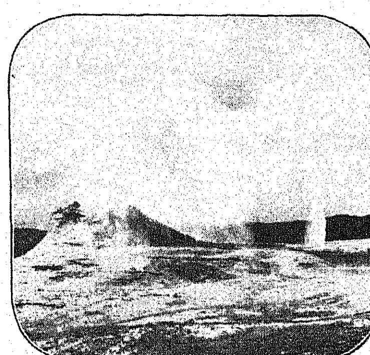


FIG. 221.
Silicious crater of geyser in Yellowstone Park.

Somewhere there is a source of heat, which seems to be located at no great depth (Fig. 222). Perhaps

in certain cases, it is a lava intrusion that has not quite reached the surface. In a geyser there is apparently a narrow tube extending into the earth; and in this the water is heated in one part more than elsewhere. If the tube were broad enough, this would merely produce boiling; but being of small compass, the circulation of water and steam is prevented, and so energy is gathered for an explosion. Geysers may be made artificially by heating water in a long glass tube until the steam causes an explosion.

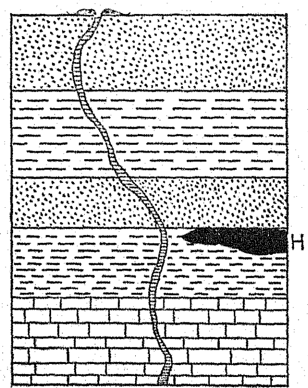
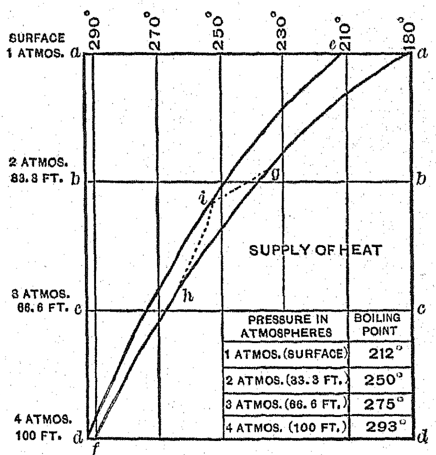


FIG. 222.
Diagram to illustrate the heating (by *H*, a buried lava mass) of the water in a geyser tube.

At the surface of the ground, the boiling-point of water is about 212°; but the pressure of a column of water raises the boiling-point, and so, at a depth of some feet below the surface, the boiling-point in the geyser tube is higher than 212°. Suppose that at this place there is a constant supply of heat, which raises the temperature of the water so high that the boiling-point for that particular depth is reached. The expansion of the steam generated in the tube, then raises the water column and causes it to overflow. By this means some of the water is removed, and therefore the pressure upon the point which we have been considering is slightly lessened. This release immediately lowers the boiling-point nearer 212°; and so the water, already heated above this point, changes immediately to steam, causing an eruption.

Let us suppose that the boiling-point of the water at a given depth below the surface, under the pressure of the column of water above, is 230°. The water here is warmed until this temperature is reached, when it begins to change to steam. Since the narrow tube prevents its ready escape, the steam lifts the water in the tube, causing some of it to overflow. Thus there is a loss of, we will suppose, several pounds of water, and hence a release of just that much pressure. So the boiling-point at the place under consideration is suddenly lowered to 228°. Therefore, the water here has a temperature higher than the boiling-point for that particular pressure, and nothing remains for it to do except to suddenly change, with explosive force, to steam. The length of time required to bring about these peculiar conditions determines the period of the eruption, which may be regular and frequent, or on the other hand, very irregular.



PRESSURE IN ATMOSPHERES	BOILING POINT
1 ATMOS. (SURFACE)	212°
2 ATMOS. (33.3 FT.)	250°
3 ATMOS. (66.6 FT.)	275°
4 ATMOS. (100 FT.)	293°

FIG. 223.

Diagram to illustrate cause of geyser eruption. Horizontal divisions, degrees of temperature; vertical divisions, depth in feet and pressure expressed in atmospheres (one atmosphere about 15 pounds to the square inch). Boiling-points for the different pressures given in the table. Line *af* represents temperature in geyser tube at depths down to 100 feet. This is always below the boiling-point for the depth. The curve of boiling-point at different depths, and hence different pressures, shown by line *ed*. A supply of heat raises the temperature of a part of the line *af*, at *gh*, until it reaches the boiling-point at *i*, about 40 feet below the surface. Then steam is formed, and shortly an explosion.

CHAPTER XX

METAMORPHISM AND ORE DEPOSITS

Metamorphism

Nature of Metamorphism. — Hardly are rocks deposited in beds, or otherwise accumulated, before they commence to undergo change. Sometimes it is consolidation by the deposit of cement, again it is a difference wrought in the minerals. At times the alteration causes decay, which weakens the rocks, while again the changes make them stronger. So rocks are constantly and steadily varying; but the term *metamorphism* refers to a particular class of changes by which the minerals are altered, and one rock gradually evolved into another, which differs more or less completely from the original.

Among the strata this process of metamorphism may be seen exhibited in various stages. In reality, nearly all rocks show some beginnings of metamorphism, the result of the constant work of the ever-busy agents. Let us look at some of the rocks which show decided changes of a metamorphic nature. Suppose it to be a limestone. This is naturally made of amor-

phous carbonate of lime, either in the form of large fragments of shells, or else smaller particles of the calcareous portions of animals. The first change that is noticed after consolidation, is the growth of crystalline bits of calcite, whose cleavage surfaces sparkle as the rock is turned in the light. This may proceed until a sugary white *marble* is formed; and in the large masses of this altered or metamorphosed limestone there is seen a kind of banding, like that so often noticed in the bluish-white marbles.

Or the rock which is changing may be a clay. If so, the first difference that is noticed is transformation to a dense, hard rock. This may then be altered to a *slate*, which splits easily into many different layers. This *slaty structure* is due to the presence of innumerable micaceous flakes of minerals. All these are arranged with their flat faces parallel, so that the rock splits in this direction in a manner somewhat analogous to the splitting of a sheet of mica. These newly formed minerals may not admit of detection with the eye, though their presence is shown by the shiny surfaces of the slate; but the microscope will reveal their presence. Here then, this rock has undergone another kind of change. In the limestone it was chiefly an alteration of amorphous to crystalline carbonate of lime; but in the slate, a *new mineral* has grown out of the complex elements of the clay.

This change of the clay stratum may proceed with the development of other new minerals; and if the conditions are favorable, mica flakes may appear, and then the rock be transformed to a *mica schist* (Fig. 45). Mica schist may be produced from various classes of rocks; but in each case it is the result of a change in mineral composition. Instead of mica, the new mineral may be hornblende or some other, thus producing hornblende schist, etc. Here again, among these products, one of the most noticeable features is the banding of the minerals, producing a *schistose structure*, along which the rock easily breaks. Even further change may take place; and out of the fine-grained clay or other rock, there may develop a coarse, crystalline product, in many respects resembling a granite, except that the minerals are more or less distinctly banded. This is a *gneiss* (Fig. 46).

Frequently the rock resulting from these variations, is of the *same chemical composition* as the original, the change having been merely in the relation of the minerals; but in other cases there have been fresh elements actually introduced from outside, so that there is an *addition* of new mineral matter. This transfer of materials is evidently the result of water action, and the substances brought have been carried in solution. In many cases the elements thus transported, and the changes produced in the minerals, indicate that the

carrier, water, has been heated. One of the best illustrations of this water action in moving materials during metamorphism, is found in the *quartzites*, which are really altered sandstones firmly cemented by quartz, so that the rock looks like a solid mass of quartz. Sometimes the deposited quartz has gathered, in the form of true crystals, about the grains of sandstone, each grain serving as centre to a growing crystal (Fig. 224).

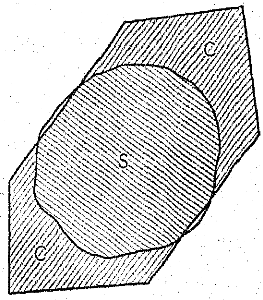


FIG. 224.
Diagram to illustrate growth of a quartz crystal (*C*) around a sand grain (*S*).

During metamorphism there are often indications of *high pressure*, — now in the crumpling of folded layers, as paper may be crumpled (Figs. 225 and 228), again in the squeezing out of pebbles, even those of quartz, into elliptical forms (Fig. 226), or more rarely, into sheet-like layers. Among these signs of pressure, there is sometimes evidence of flowing, which indicates the *presence of heat*. Furthermore, rocks are not infrequently crushed, and the minerals broken as a result of great pressure. This crushing is also accompanied by movement, producing a banded structure in the rock thus metamorphosed.

In all these cases, there comes about an arrangement of layers, which may not lie parallel to the original

bedding, but in a direction making a high angle with this (Fig. 227). These layers in the metamorphic rocks are usually of minerals of different kinds. When examined in their place in the earth, it is found that the layers of banded minerals are parallel to one another over considerable distances, as if some powerful force had been at work throughout the area.

Fig. 225.

Crumpling in a metamorphosed limestone.

If the metamorphism has taken place in sedimentary rocks, the changes are often so pronounced that not only is the original nature of the rocks hidden, but even the stratification is destroyed, and nothing remains to tell whether the altered rocks were originally sedimentary or igneous. Possibly some small portion here or

there, has escaped complete change, so that from these we are able to discover the original condition.

Position of Metamorphic Rocks. — It may be said that metamorphic rocks are found in the earth's crust in three positions: (1) near some mass or bosse of intruded igneous rock; (2) in mountains, deep below the original surface, and in the very core; (3) among the most ancient rocks, particularly the lowest and oldest of all, the Archean. The first are small in area, the second usually fall within relatively narrow zones, and the third occur in great areas.

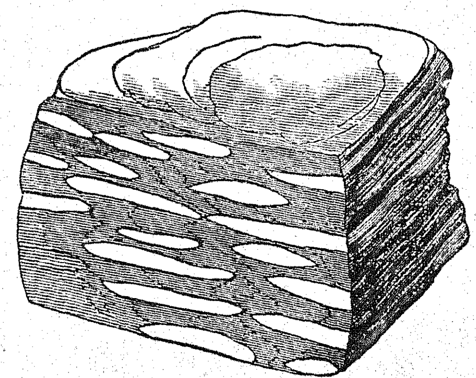


FIG. 226.

Diagram showing flattening of pebbles by the pressure during metamorphism.

Not many years ago it was believed that all these metamorphic rocks represented the most ancient of strata, and were a part of the original crust of the earth; but careful studies have shown that this is not so, and that many very much altered rocks belong to later ages, and are really transformations of sediments belonging to the same general age as deposits of shales, limestones, and sandstones in neighboring regions.

For instance, this is true of a good part of the rocks of New England, which were all once supposed to belong to the very oldest epoch of the earth's history. Of the truly ancient rocks of these early ages, the Highlands of New Jersey and the Adirondacks of New York furnish the best known instances in eastern United States, though parts of New England are undoubtedly of the same period.

Those metamorphic rocks that are situated in mountain cores, are in places where there has been great pressure and movement, and probably much heat. The same is true of the metamorphic rocks found near igneous intrusions. Perhaps the most ancient Archean strata really represent the original crust of the earth, or else deposits made and changed at a time when there was much higher heat in the surface rocks than we find at present. Of this, however, there is no definite proof; and in the absence of data, we can only speculate.

Causes for the Changes. — Since there are rocks whose changes can be seen and studied, it is well to content ourselves for the present with a consideration of these, without assuming that the same variations have occurred in the metamorphic rocks of more ancient date. Any constant application of high heat, especially if accompanied by the work of water (which is always present in the rocks), will cause the minerals to change. Under sufficient heat, the rocks will melt, though in real metamorphic beds there is no sign of actual melting.

If allowed to work long enough, these changes will cause a recrystallization of the elements. Perhaps the water will take quartz into solution in one place,

carry it to another, and there *build* a mineral, as is done when quartzites are cemented by a deposit of silica. Or possibly the *form* of the mineral will change from the amorphous condition to the crystalline, as in limestone. Or certain minerals, like the kaolin of clay, combining with other materials, and altering in various ways by the complex *chemical action* of water, will build up new minerals, such as mica, feldspar, hornblende, etc.

Pressure will aid the work; and if the conditions are favorable, cause the particles to slip, either producing crushing, or else a movement much like the flowing of a viscous body such as wax.

Pressure is also important in determining the *arrangement* of the newly growing minerals. As they grow, they develop in the direction of least resistance, which is at right angles to the direction in which pressure is applied. So among mountains, with the pressure coming from the sides, minerals, and consequently the resulting schistose structure or slaty cleavage, will develop at right angles to this; that is to say, in the direction of the axis of the folding. This is often beautifully shown among mountains, where the slaty cleavage crosses the strata indiscriminately, but always extends in a single direction (Fig. 227).

Among mountains where metamorphism has been in progress, we often find some layers very much changed, while others, less easily altered, but subjected to the same conditions, are hardly metamorphosed at all. Or the same layer, traced from one place of marked

change, where the pressure was great, gradually becomes less and less metamorphosed as we pass to portions of the mountains, where for one reason or another the pressure was lessened.

Again, in the close neighborhood of a great mass of intruded granite, the rocks may be so highly altered that we cannot easily tell what they originally were

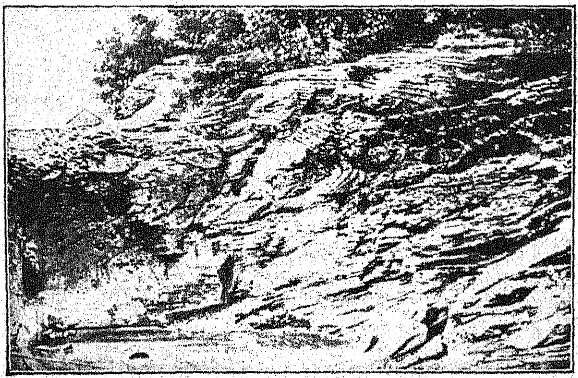


Fig. 227.

Photograph in a slate quarry, showing slaty cleavage crossing the beds of folded rock.

(Plate 15), while as the distance from the source of heat increases, the former condition becomes more and more distinctly apparent, until finally the unchanged rock appears.

Sources of the Heat and Pressure. — The source of the water, which is so important an agent of meta-

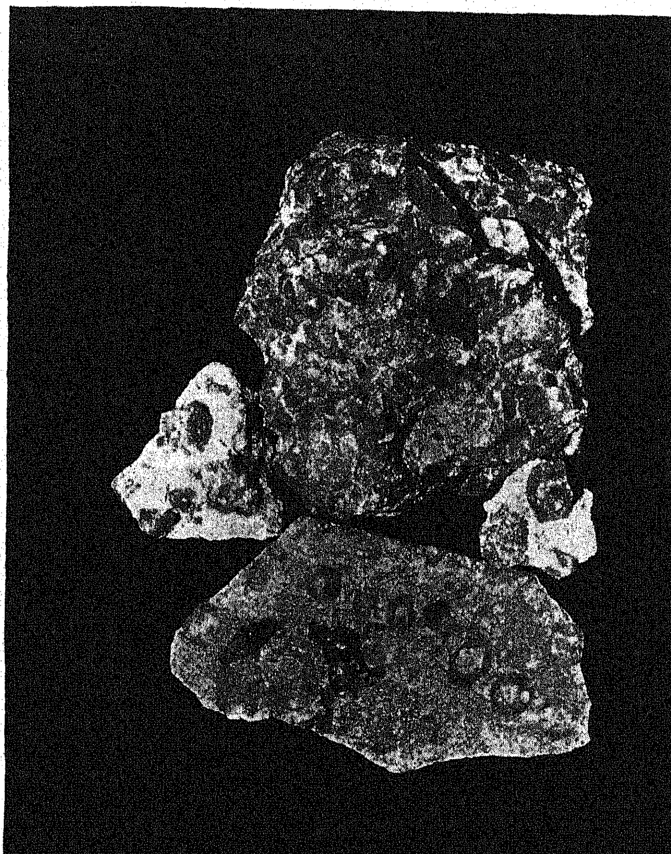


PLATE 15.

Photograph of specimens of rock taken from different parts of a metamorphosed limestone bed. Right-hand figure, the original limestone conglomerate. Other specimens containing many new minerals, notably distinct crystals of garnet.

morphism, is not difficult to find, for this substance is always present in the rocks.

The heat that aids in the alteration may be of volcanic origin, either because of neighborhood to a volcanic vent, or else to some buried mass of intruded lava. Or to some degree it may be the heat originally in the earth. At present the burial of the rocks to depths of many thousands of feet (some have been buried beneath more than 40,000 feet of strata), must cause a great increase in heat.[1] Perhaps in the earlier ages of the earth, burial less deep than this would produce higher temperatures, for then the earth was not so cold near the surface.

The folding of mountains, with the consequent slipping of the rocks over one another, also causes heat, just as we may heat two stones by rubbing them together; such heat, thus generated by mountain growth, may aid or even cause metamorphism. Then, finally, heat may result from chemical change as water passes down into the earth, just as we may heat a solution by adding some substance which induces a reaction.

From most of these causes, pressure may also result (Figs. 225 and 228). The intrusion of rock masses exerts pressure upon the strata on all sides of the intruded material. Chemical change, resulting from

[1] For the temperature increases about 1° for every 50 to 60 feet of depth.

the action of water, may cause an enlargement of the area occupied by any given mass of rock; and from this source also, pressure will be applied to the strata on all sides. The folding of mountains is a potent cause of pressure, — perhaps the most important of all.

Given pressure and heat, water becomes a powerful

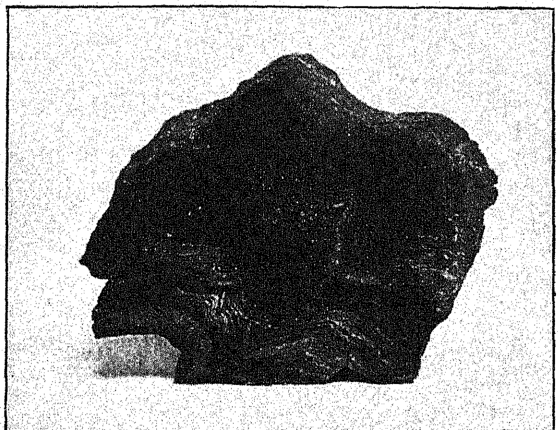


Fig. 228.

A crumpled gneiss, showing presence of pressure during formation.

agent of change. With a temperature of hundreds of degrees, it takes many substances into solution, and working with these, causes changes of the utmost consequence. It has not been possible to imitate these variations of rock condition by actual experiment; but the evidence of the operation of these agents in the crust of the earth is thoroughly convincing.

Kinds of Metamorphism. — While pressure, heat, and water are commonly combined to cause metamorphism, there are cases in which one of these acts alone, or where the importance of one greatly overbalances that of the others. Where the changes have resulted mainly from pressure, the term employed is *dynamometamorphism;* where water has been the most important factor, *hydrometamorphism;* and where heat has predominated, *thermometamorphism.*

In the vicinity of igneous masses of intruded rock, the changes in the neighboring strata have been most marked close by the intrusion, or exactly at the contact. This alteration is recognized as *contact metamorphism.* But in great and extensive mountain folding, the alteration has been much more widespread, producing *regional* or *general metamorphism.* During this widespread change over great areas, as for instance over nearly the entire state of Vermont, the western part of Massachusetts and Connecticut, and the eastern border of New York, a condition of mountain folding of an extensive sort has changed the strata so decidedly that their original condition is often quite impossible of determination. Here the profound, and at present even mysterious forces of nature, have conspired to produce changes, whose character we are but just beginning to understand.

Ore Deposits

The Original Source of Ores. — Determinations of the specific gravity of the earth, show that the average weight is greater than that of the rocks at the surface. This leads to a common belief that the interior is either metallic, or else contains a greater percentage of heavy metals than of the lighter elements. This is also indicated by the fact that many igneous rocks are bringing

up a considerable supply of metal. An analysis of lava will always show much iron, and very often measurable quantities of copper, lead, silver, etc.

As the lava rocks decay at the surface, and enter into the formation of the sedimentary strata, this ore supply also goes into these accumulations; and with the later action of water, in favorable places, may be gathered into beds which can be mined with profit. Still, where there is one such accumulation worth mining, there are many hundreds too poor to work.

Classification of Ore Deposits. — We may divide ore deposits into three classes: (1) Erupted, (2) Mechanical, (3) Chemical. The latter, by far the most important, admit of much subdivision.

Erupted Ore Deposits. While every lava contains goodly quantities of ore, this is usually too scattered to attract attention. In only a very few cases is this a source of extensive deposits, and these instances are mainly of iron. Some nickel deposits are believed to be of the same origin. In Greenland there are bunches of pure metallic iron in a lava.

Mechanical Ore Deposits. As rocks decay, the more durable minerals resist disintegration. If for instance, a rock containing gold begins to disintegrate, since the gold is not readily destroyed, it endures in its metallic condition, while the other constituents of the rock crumble to bits.

Being heavy, the gold resists removal by running water more than do the lighter minerals. So in being carried down stream, or in being washed backwards and forwards by the waves on a beach, the gold accumulates in pockets or layers, from which it may be mined with profit. This is the source of the stream

and *placer gold* of the west, of Russia and Australia. In the Malay peninsula, tin is obtained from the same source; and all the platinum that is mined comes from similar gravels. Aside from these three metals, there is little ore of value gained from such sources.

Chemical Ore Deposits. It is impossible to consider all the ways in which ore deposits are accumulated by means of chemical change. The three chief varieties are: —

(1) *True veins*, or those accumulated in fissures of various kinds; (2) those formed by *replacement* of other minerals; (3) *concretionary* deposits.

TRUE VEINS. These, which are the most valuable of all the ore deposits, are formed in fissures or other cavities in the earth. There are various kinds of cavities in the rocks, such as (1) joint planes, (2) gas cavities, caused by the expansion of steam in lava rocks, (3) caves produced by the solvent action of water upon soluble substances, as carbonate of lime, and (4), most important of all, the cavities formed by faulting.

As water passes through the earth, it is dissolving here, changing there, and depositing elsewhere. It is by this action that ores are accumulated in cavities. Ordinarily the substances carried are other than metallic minerals; and so in such cavities we most commonly find quartz, calcite, and similar minerals of no value, though sometimes ores are thus gathered into beds.

Let us suppose that the cavity which is to be the seat of deposit, is a fissure or fault plane, leading deep down into the earth; for it is in such cavities that we discover the most valuable ore beds. Water is entering this fissure from some region where it has obtained a high temperature. Passing upward through the cavity, the water becomes less highly heated, and finally, reaching the surface, flows out as a hot spring (Fig. 229 and p. 362).

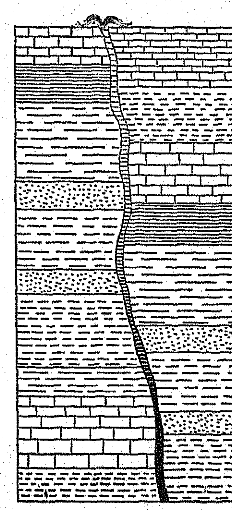


FIG. 229.
Diagram to illustrate vein formation. A fault plane filled with water. Intensity of shading indicates high temperatures.

As it goes on its journey, the water is able to dissolve mineral substances because of its high temperature. By this means it takes from the rocks some elements which transform it to the condition of a powerful acid, or of an alkali; and thus strengthened, acting upon minerals which contain valuable metals, the water is able to take these in solution in some chemical combination.

Passing upward, the water cools; as it loses heat, it has less power of solution, and begins to deposit. It may hold several substances in solution,—such, for instance, as quartz, calcite, and an ore of iron. At one time or place it deposits quartz on both walls of

the cavity. Later, with a slight change in conditions, calcite is precipitated, while later still a deposit of the iron ore is made; so that on each wall of the vein there are three bands of minerals. This *banded structure* is common in true veins, and oftentimes there are many bands of different minerals in a single vein (Fig. 230). The valueless minerals (usually the *non-metallic*, such as quartz and calcite) are called *gangue* or *veinstone*. The metallic mineral (in this case iron) is known as the *ore*.

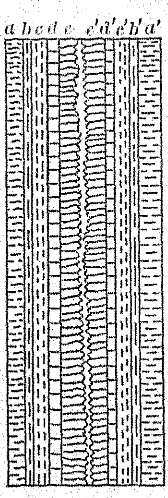


FIG. 230.

Cross-section of vein, showing banded structure.

Not only may decrease of temperature cause deposits, but the water of the vein may be subjected to loss of some of its materials. Or it may take up other substances, so that, as a result of the change, something is necessarily deposited, —just as we may precipitate certain substances from solution by the addition of others, as one sees commonly illustrated in the chemical laboratory. The mineral vein is the site of great chemical change, one of whose results is the filling of the cavity with gangue and ore. Even ores of gold and silver may be thus gathered into veins.

REPLACEMENT DEPOSITS. When a buried tree is enclosed in rock, the wood fibre, by the action of percolating water, may be replaced bit by bit, with particles of silica (Fig. 231). We then have a silicified or petrified tree, in which the woody structure is perfectly preserved, though the tree is changed to stone. Or the shell of an animal, composed of carbonate of lime, like the shell of the oyster or clam, may be re-

placed little by little, until it is a shell of silica, or of an ore of iron, or some other mineral.

In the same way as with the shell, beds of rock may be slowly changed by percolating water, until, instead of a sandstone or limestone, we have a bed of iron ore. As a result of this, not only are the particles of the rock replaced (Fig. 232), but even the shells that are enclosed within it are transformed to ore.

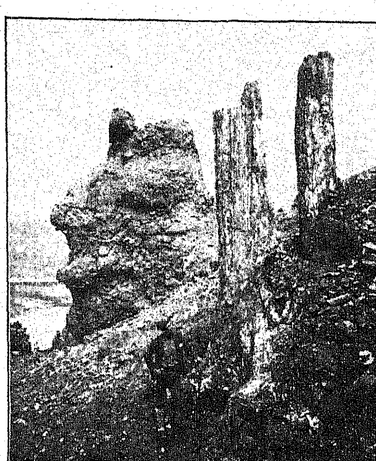


FIG. 231.
Petrified trees formerly buried in the conglomerate rock.

While other ores are sometimes made in this way, the most common replacement deposit is iron. This is doubtless due to two facts: (1) that iron ores are of frequent occurrence in the crust of the earth, and (2) that these minerals are dissolved, carried, and deposited with ease, by water whose temperature is not high. Even now in the crust, this action of replacement is commonly in progress.

CONCRETIONARY ORE DEPOSITS. The nature of concretions has already been explained (p. 275). When the mineral which is gathered into the concretion is an ore, a valuable deposit may perhaps be formed. This kind of deposit is also most commonly of iron, for the same reasons that hold good in regard to replacement deposits of iron ore.

A similar deposit, the segregation vein, is formed by the aggregation of ores into sheets during the metamorphism of rocks, where, instead of mica, hornblende, etc., iron and certain other ores gather into bands or beds. This is illustrated by the banding of metamorphic rocks.

Other Ore Deposits. Besides these, there are beds of ore formed at the contact of intruded igneous rocks, through the direct action of these heated masses. There are also deposits precipitated from solution, such as the iron ore which sometimes forms in the bottom of swamps. Other classes less common would be included in a complete study of the ores.

Conditions favoring Ore Deposits. — Considering only the ores stored up in fissures through the action of heated water, which include the most valuable ore treasuries, we see that the places where such deposits are most likely to occur are in regions of mountain growth, and particularly among mountains recently formed. This is due partly to the fact that mountains of this nature have many fault planes, and hence cavities in which ores may be deposited, and partly to volcanic action. Heat is furnished by the intruded lava which also supplies the ore for the water, for it will be remembered that igneous rocks contain ores. These are the main reasons for the importance of the Cordilleras of the west, where gold and silver and many other ores occur in veins wonderfully rich, making this region the greatest mining district of the world.

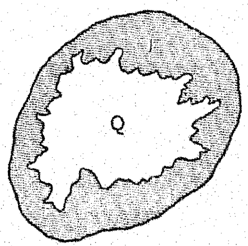


FIG. 232.
Diagram to illustrate replacement of a quartz grain (*Q*) by iron (*I*). The grain formerly extended to outer boundary.

PART III

STRATIGRAPHIC GEOLOGY

CHAPTER XXI

THE USES OF FOSSILS[1]

Introductory. — Geological study, as carried on now for about a century, and extended to all continents, has revealed the fact that the earth possesses a varied history, one chapter of which is now in progress. This history has been one of continual change promoted by the agents already discussed. It is the belief of geologists that these agents have operated in the past very much as they are operating now. There have probably been times of more rapid change; but in a general way,

[1] In this part of the book the author has departed somewhat from the usual custom in books of this kind. Commonly stratigraphic geology is made primarily a study of the history of organic life on the globe. In these pages the progress of organic life throughout geological ages is stated, but the changes in climate and physical geography, particularly of the United States, are the main themes. The omission of the more strictly palæontological aspect of the subject is not due to any lack of appreciation of its value, but rather to the belief that this topic is too important to be treated as would be necessary within the limits of an elementary book. A mass of names of animals and plants is meaningless to the pupil who has not had more training in biology than can be expected of most students in the secondary schools. Therefore, the mere catalogue of names is strictly omitted. The teacher would do well to have a set of common and typical fossils in the laboratory, and to make a study of the fossil fauna of the neighborhood, provided the school is situated in a favorable region.

and on the average, the history of the present is merely a continuation of the past. Of this there are so many evidences, that it is all but a universally accepted principle in geology.

History involves stages of progression. For any adequate understanding of the earth's past, we must seek to recognize such stages. Indeed, until the early part of this century, when a means was found of distinguishing the ancient from the mediæval and modern periods of the earth's history, the science of geology cannot be said to have really had its birth. To William Smith, an English surveyor, belongs the honor of first finding this clue. He discovered that animal remains in the rocks, or fossils, furnish a means of determining how ancient the strata are; and from that time to the present, the study of these remains has been one of the most important features of geology.

The Fossil. — The name *fossil*[1] is now applied to any organic remains, preserved in any natural deposit in or on the earth's crust, whether this be an animal or plant, or any part of such organisms. So it may be either an entire animal or plant, a fragment, an impression, or a cast of one. It may be the leaf or seed of a tree, or its bark or root; or it may be the shell of a clam, the tooth of a shark, or merely a print left in the rock by either of these.

[1] Originally meaning anything dug up, either mineral or animal.

In some rocks these remains are abundant, in others scarce or altogether absent; but whenever found, they tell us something of the earth as it existed at the time when the rock in which they occur was formed. Had there been preserved a goodly percentage of the animals that have lived on the globe, we should now have preserved in the strata, a complete record of the animal life of this planet; but for various reasons, our account is extremely imperfect and fragmentary.

Conditions favoring the Preservation of Fossils. — As rocks are accumulated, organic remains are buried there in greater or less quantity. The most favorable place for such burial is in the sea; for here, in addition to the abundance of life, there is rapid formation of sediments, which will cover the fossils and prevent destruction. Moreover, the very presence of the water checks decay. In less degree, the sediments of lakes are favorable for the entombment of plant and animal life. On the land, on the other hand, organisms dying in the air speedily decay, and are not usually buried. Therefore the record of life in the rocks is chiefly a record of salt and fresh water organisms.

Upon the land there are a few places where fossils may be well preserved. In caves the chemical deposit of carbonate of lime often protects the remains of animals and plants that happen to fall there. Lava flows, and ash deposits too, cover organisms and protect them from destruction; and swamps,

being places from which the action of air is partly excluded, also serve as repositories of fossils.

In swampy places, the rapid destruction of organic remains is prevented by the preservative effect of certain vegetable acids produced by the partial decay of the swamp plants. As a result of this, coal beds, with perfect impressions of delicate ferns, have been preserved for long ages. Another way in which land organisms may be protected from destruction, is by being drifted into lake or sea, and there buried beneath the gathering sediments.

Even where the conditions are favorable for animal preservation, as a rule only the most durable parts remain.[1] The shells of animals, and the teeth, bones, and other more indestructible parts, are the commonest of animal fossils. Those creatures that are destitute of the harder substances have little chance of preservation; and hence whole races of animals have lived and passed away without leaving us even a trace of their existence. The most complete records have been left by the shell-bearing animals of the sea. Some beds of rock are almost entirely made of their remains, and throughout the strata they are abundant as fossils.

Even when animals or plants have escaped decay after death, and become entombed in the strata, the danger of destruction is not over. The rocks in which they are enclosed may be so affected by metamorphism that no trace of the fossils is left. And again, in some rocks the action of percolating water is able

[1] There are exceptions to this. For instance, in the National Museum at Washington, there is the distinct impression of a delicate jelly-fish upon the surface of a slab of rock, formed ages since.

to remove the fossils and obliterate all signs of their existence. Other things being equal, the older the strata, the more liable are the organic remains to such annihilation, for they have been exposed the longer to these agents of destruction. Therefore, in many of the older strata, fossils are scarce and hard to find.

Imperfections of the Life Record. — From the above, it is readily seen that one of the most important reasons for the imperfection of the known record of the life of the earth, is the fact that of all the countless millions of animals and plants that have lived and died, only a very small fraction have found preservation in the rocks, in any permanent and recognizable condition. Among land animals, this failure to be preserved has been so marked that our knowledge of the land life of the past is unfortunately very slight.

In addition to these difficulties, knowledge is hindered by the fact, that of those creatures which have been preserved, many have been destroyed by metamorphism or solution. This has robbed us of much of the earlier record, and indeed, so far as exploration has yet gone, has left us without any account of the life that at the outset peopled the earth. Then too, denudation has been so constantly and effectively at work, that but a small part of the sedimentary rocks originally deposited, now remain.[1] To be sure, we have rocks of all

[1] This of course applies only to the land rocks. What exists in the ocean we have no means of learning.

ages since the first; but these are merely fragments that have chanced to escape destruction.

To construct a record from this fragmentary portion of the sedimentary series, is difficult and in some cases impossible. Even had the original record been complete, there would be many gaps where rocks have been removed; but starting with an already fragmentary series, this added cause for imperfection makes indeed a ragged page. It is like a blurred and faded manuscript, which, moreover, comes down to us all tattered and torn.

More than this, even of the organisms that have been preserved, only a portion are as yet discovered. Rocks deep in the earth have never been examined. Even in well-studied regions, it is usually only the very surface that can be explored. Most of the fossils are buried beneath the soil or layers of other rocks; and only here and there, in a ledge, or a cliff, or a shaft that has been sunk in the earth, can we search for the entombed remains of those organisms that have passed away. So as exploration proceeds, our knowledge of the earth's past is continually increased, and each year brings new and important discoveries.

In spite of these difficulties and imperfections, enough has been learned from the study of fossils to tell the outline story of the earth's development; but only enough to make us see the incompleteness of this

sketch, and eagerly seek for more knowledge. The story is one of constant change and of general progress from lower to higher forms of life. Strange animals and plants have come upon the earth, and after altering in form and nature, have disappeared, while their place has been taken by others; and always, as a result of these changes, there has been a general evolution and advance.

Uses of Fossils. — The chief use of fossils is found in the hints that they give us concerning the climate and physical geography of the past, in the evidences that they furnish of evolution, and in their value in the construction of the geological time-scale or chronology.

Climate. Fossils tell us much of importance concerning the climate of bygone ages. Frozen in the earth of Siberia we find bodies of the mammoth, which in many respects was like the elephant, though it had a covering of hair for protection from the cold. The presence of these animals tells us that at one time the climate of this bleak land was less severe.

Far to the north, within the Arctic circle, and directly beneath the fields of perpetual ice, the rocks contain fossils of animals and plants which are now confined to more temperate zones. There are evidences that changes from warm to cold, and the reverse, have alternated in the ages of the past.

Physical Geography. Fossils also teach us facts about the past changes in land and water. The presence of land is shown by the fossils of certain creatures which habitually live near the coast, or by the presence of land animals and plants that must have drifted into the sea, and thus been buried in marine sediments. With marine fossils we prove the presence of ocean water; the existence of lakes, where now there is dry land, may often be told by the fossils of fresh-water creatures.

Some animals live in clear, others in muddy waters. Certain creatures, like corals, exist where warm ocean currents flow; and so, by their distribution we may sometimes trace the extension of these great equatorial streams. Again, in two places not far apart, the fossils of the same period are quite unlike, and we feel certain that they were separated by some barrier, as the Bermudas are now separated by deep sea from Cape Hatteras. Then finally, the species of the two zones begin to intermingle, and from this we know that the barrier has been removed.

Still another way in which fossils help us to an understanding of past changes, is by determining the value of an unconformity (p. 321). Two sets of strata rest together, one on the other; but between the sets there is a break or unconformity, which represents a time of dry-land condition between the deposit of the

first and the second series of strata. If there were no fossils, we could gather only the fact of the break; but finding remains in the two sets of strata, we can determine the geological age of each, and thus gain some idea of the lapse of time occupied by the dry-land condition. It may have been long enough for the animals to entirely change in kind.

Evolution. As has been stated, one of the revelations made by these organisms is that of change, progress, and development. From the study of fossils, the doctrine of evolution has received great support. With the change of conditions, forms of animal and plant life have varied, new species have been evolved, races have come and gone, and always there has been indicated a grand forward movement. The earth has slowly changed for the better.

Chronology. Since there has been this progress in animal and plant life, it follows that the rocks of the past contain a different assemblage of fossils from those stored in more recent strata. Therefore, if we know the kinds of animals that lived at *different* periods, we may by means of these identify the rocks. If in any place we should have a series of strata, one above the other, representing deposits made from the dawn of time to the present day, there would be found in these a record of the most important changes in animal and plant life. The lowest strata would contain

the oldest fossils; the youngest would be found in the highest.

While there is no such coherent record as this, there are many places where thousands of feet of rocks have been accumulated, one upon another. A careful study of these, then, will give us some life record for that part of the history which they represent. Elsewhere similar sections bear witness to other ages; and so, by piecing the fragments together, we have in each continent a fairly complete section from the oldest to the youngest rocks, and in them remains of animals from the very early ages to the present.

It was this fact, based upon the *law of superposition*,[1] that gave to William Smith the clue upon which he laid the foundation of the present geological time-scale. Studied carefully, in many places and in many lands, fossils have given us the means of telling the relative age of strata; for thus we have been able to learn what kinds of animals characterized the different ages. To illustrate roughly, birds did not appear until a certain age; and hence, if we find the skeleton of a bird in the rocks, we fairly conclude that the strata containing it were deposited at some period later than the time of the first appearance of these creatures. Finding other fossils in the same bed, we may tell with certainty just what the age is, and just where in the

[1] That in a section of rocks, the oldest are the lowest.

geological time-scale the rock belongs. With our present knowledge, we are able to determine the general age of any fossil-bearing rock found in any part of the earth.

Early Attempts at a Division of the Strata. — Before the value of fossils was known, it was recognized that there were differences in the age of rocks, and rough attempts were made to classify them. Since then the geological time-scale has gradually grown to its present condition. The names for the divisions furnish a crude record of this growth of ideas, and the time-scale thus contains a partial history of the changes in opinion.

At one time rocks were divided into three classes, — Primary, Secondary, and Alluvial, — the Primary being the oldest, the Secondary, later rocks of sedimentary origin, and the Alluvial representing the unconsolidated surface rocks. Later these were divided into other classes, giving us Primitive, Transition, Secondary, Tertiary,[1] and Alluvial. After this the belief that rocks of different ages were characterized by some mineral peculiarity, led to the introduction of other divisional names, such as the Cretaceous or chalk formation, the Old Red Sandstone, the Carboniferous, etc. Still later, other names were introduced, or substituted for some already in use, and these were based upon the study of fossils. In some cases these divisions were named for the place in which the study was made, and where the rocks were well developed, — as Devonian, for Devonshire, England, and Permian, for the province of Perm in Russia.

Basis of the Geological Time-Scale. — The basis for the present division of the rocks into groups, is the fossils that they contain. The *true* life progress has been gradual and complete, without any abrupt break on the basis of which we can draw sharp lines of divi-

[1] A name still used.

sion. Still, in some cases, after a series of rocks was formed, with the enclosed fossils, these strata were raised above the sea, and after remaining as land for awhile, were again submerged, so that on these were deposited other strata with an unconformity between. During the gap, or the period represented by the unconformity, time enough had elapsed for a change in the conditions of life to occur. Therefore, the fossils of each set of strata are quite distinctive of their periods of formation; and being carefully studied, furnish a means of telling the age of rocks of the same period elsewhere. To each of these groups of strata, names are given, such for instance as the Devonian and Silurian; and in other parts of the world all rocks with similar groups of fossils are recognized as belonging to the same periods.

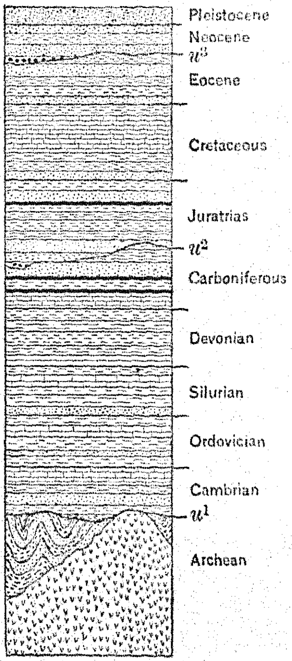


FIG. 233.

Diagram to illustrate superposition of rocks of the various ages. Three unconformities (u) also shown.

By careful studies and comparisons, made in different countries, a time-scale has been built up, and the his-

tory of the earth divided into ages (Fig. 233). In some places, where unconformities exist, the line between two successive ages may be sharply drawn, because a portion of the record is missing. For instance, to make a comparison, in a house it would be difficult, without painstaking measurement, to say where the exact line of division between the right and left sides passes; but if a section should be taken out of the middle, this division into two parts could be easily seen, and no one could doubt where the line of separation should fall. The same is true of rocks.

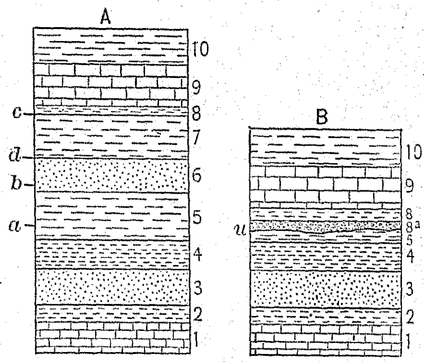


FIG. 234.

Diagram to illustrate basis of division of strata into ages. In Fig. *A*, ten beds (1–10) are accumulated. The line between 6 and 7 marks the arbitrary division of rocks which have gathered without a break. In Fig. *B*, another section of the same beds near by, strata 1 to 6 were deposited, then elevated, and eroded until the line *u* (unconformity) was reached. During this time, layer 7 was accumulating elsewhere, but not on the land at *B*. So all of layer 6 and part of 5 were removed, and 7 failed to be deposited. Hence the unconformity *u* marks a sharp contrast between the rocks of the upper age and those of the lower. Naturally, as in *A*, they grade into each other, and hence the divisional line is difficult to draw; but here in *B* it is easy.

Sometimes a part has been removed or is wanting, and here the division is readily made (Fig. 234); but in other places, as for instance in New York, the divid-

ing line between certain periods, as the Devonian and Silurian, is not at all easily drawn, although at some distance above or below, there is no difficulty in telling by the fossils contained in the rocks, which is Devonian and which Silurian.

When we speak of *age* in the geological time-scale, we do not mean a period of *exact time*, as in the ordinary use of the term. We cannot measure the history of the earth in years; but the time-scale serves as a convenient means of dividing this history into *stages*. Similarly the early history of man is divided into Palæolithic and Neolithic stages, based upon the different kinds of instruments he used as he was developing from savagery to civilization.

Nor do we mean, when speaking of the Silurian of Europe, America, and Australia, that in these three widely separated continents, the Silurian represents the same age in real time. At present the animals of Australia differ greatly from those of other continents; and probably in the past, as now, very different kinds of animals existed simultaneously in widely separated areas. Still the rocks of a given age in different regions were undoubtedly formed at *nearly* the same time.

What similarity of fossils really does show, is the *stage in development* which the animals of that period had reached. At some time animal life, the earth over, had attained a certain stage of development. In different quarters of the globe this might have been at very different times, for animals may have developed more rapidly in Europe, for example, than in Australia. Again, we may borrow an analogy from the history of man. Even a half-century ago, men in various parts of the earth were

using stone implements (and some still use them); they were then in the stone age, or stage, while in Europe this stage was passed through many centuries since.

To the divisions of the strata thus made, various names are given for the purpose of simplifying the study. These divisions are first into Groups, which are again divided into Systems, and these into Series, which themselves are divided into Stages; or using the idea of time as a basis, the corresponding divisions are known respectively as Eras, Periods, Epochs, and Ages.

The greater divisions into Groups or Eras, and the subdivisions into Systems and Periods, are so large that they may be recognized in widely separated countries; but the smaller divisions, into Series or Epochs, are so local that they can be distinguished only within limited areas. So the Series or Epochs of New York are given certain names, those of California others, those of India others still, and in each case the names applied are derived from some local feature of geography, usually some place where the rocks of that particular epoch are well developed. The names of the larger divisions are the same all over the world, and are everywhere recognized by the same general kinds of fossil organisms.

Upon this basis the following geological time-scale is constructed, the oldest groups being placed at the bottom. For the minor subdivisions, names commonly in use in the eastern part of this country are introduced.

THE GEOLOGICAL TIME-SCALE

GROUP OR ERA.	SYSTEM OR PERIOD.	SERIES OR EPOCH.
CENOZOIC. Mammalian Era.	Pleistocene.[1]	Recent.
		Glacial.
	Neocene.[2]	Names of subdivisions based mainly upon the south and west.
	Eocene.	
MESOZOIC. Reptilian Era.	Cretaceous.	
	Juratrias.[3]	
PALEOZOIC. Era of Invertebrates.	Carboniferous.	Permian.[4]
		Coal Measures.
		Subcarboniferous.
	Devonian.	Chemung and Catskill.
		Hamilton.
		Corniferous.
		Oriskany.
	Silurian.	Helderberg.
		Onondaga.
		Niagara.
	Ordovician.	Trenton.
		Canadian.
	Cambrian	Potsdam.
		Acadian.
		Georgian.
ARCHEAN.	Huronian.[5]	
	Laurentian.[6]	

[1] Pleistocene adopted in place of the older Quaternary.

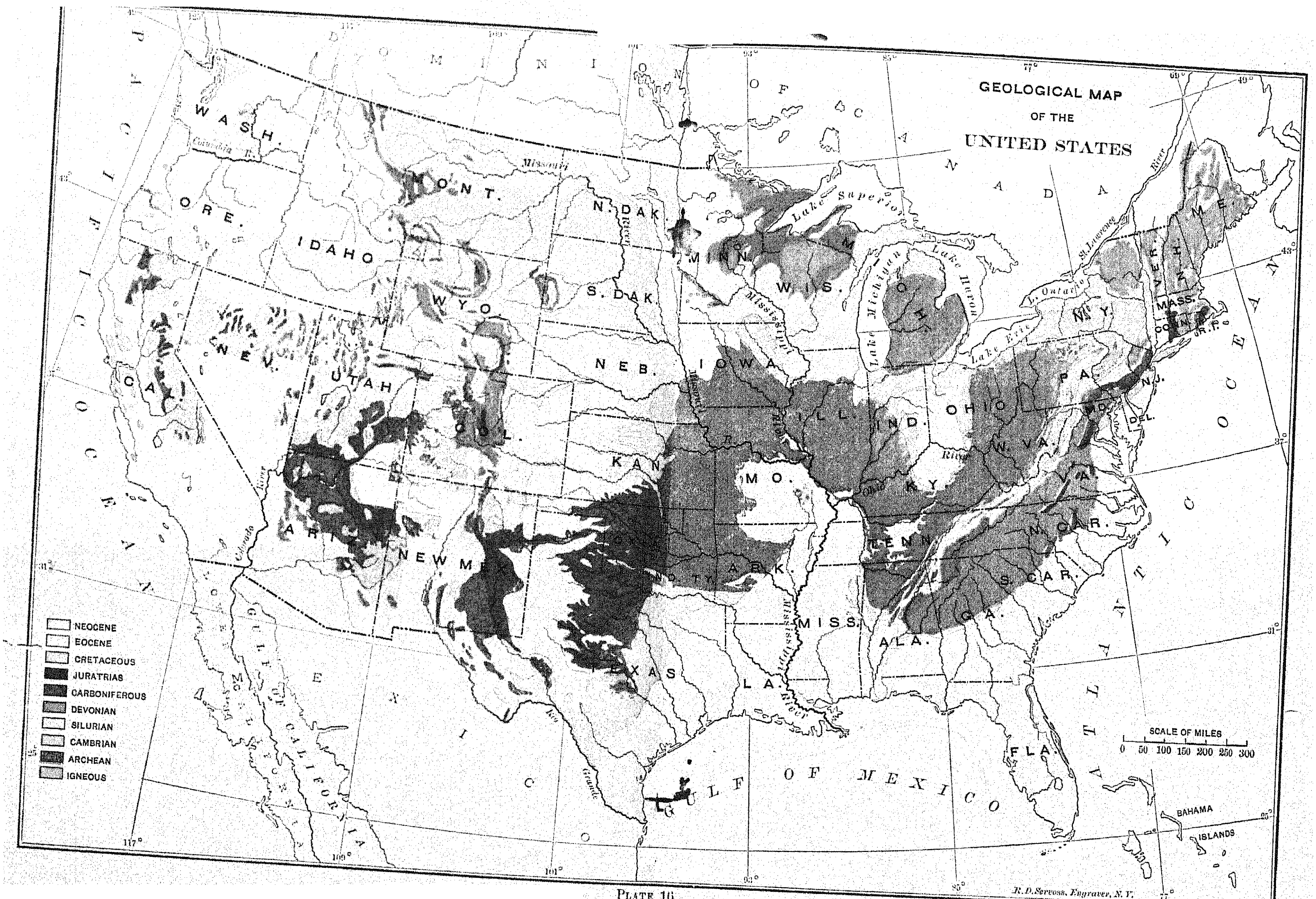
[2] Neocene and Eocene used in place of Tertiary.

[3] In Europe, Triassic and Jurassic are recognized; but the rocks of these periods in America have not been so well separated. In the east the Triassic rocks are known as Newark.

[4] Permian is given the rank of period in Europe.

[5] Nearly the same as Algonkian of the United States Geological Survey.

[6] The Fundamental Complex of the United States Geological Survey.


GEOLOGICAL MAP
OF THE
UNITED STATES
NEOCENE
EOCENE
CRETACEOUS
JURATRIAS
CARBONIFEROUS
DEVONIAN
SILURIAN
CAMBRIAN
ARCHEAN
IGNEOUS
SCALE OF MILES
0 50 100 150 200 250 300
DOMINION OF CANADA
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
MEXICO
GULF OF CALIFORNIA
BAHAMA ISLANDS
WASH.
ORE.
CAL.
NEV.
IDAHO
MONT.
WYO.
UTAH
COL.
ARIZ.
NEW MEX.
N. DAK.
S. DAK.
NEB.
KAN.
TEXAS
MINN.
IOWA
MO.
ARK.
LA.
WIS.
ILL.
MISS.
MICH.
IND.
OHIO
KY.
TENN.
ALA.
GA.
FLA.
S. CAR.
N. CAR.
VA.
W. VA.
PA.
N.Y.
N.J.
MD.
DEL.
CONN.
R.I.
MASS.
VER.
N.H.
ME.
Lake Superior
Lake Michigan
Lake Huron
Lake Erie
L. Ontario
St. Lawrence
Missouri
Mississippi
Mississippi River
Columbia R.
Colorado River
Rio Grande
Ohio River
R. D. Servoss, Engraver, N. Y.
PLATE 16

Age of Igneous and Metamorphic Rocks. — Many of the metamorphic rocks exist below the oldest fossil-bearing strata, and are hence classed in the Archean; but there are others of ages later than this. If they contain fossils, their age can be determined; but as fossils are commonly destroyed by the processes which have brought about the metamorphism, this means of classifying them is seldom available. In such cases it is often impossible to tell their age, though sometimes their relation to neighboring fossil-bearing rocks furnishes the key. In the majority of cases, however, these rocks are of doubtful age, though as careful studies continue, more and more of them are being removed from the doubtful list.

Igneous rocks contain no fossils, and hence their age is very often doubtful. Still, at times, their relation to other rocks gives their approximate age. For instance, in the Connecticut valley, near Meriden, Connecticut, there are lava flows buried in sandstones, the fossils of this enclosing rock clearly pointing to the Triassic period. Again, in New Jersey, there are intrusions of the same igneous rock cutting the same kinds of sandstone, and hence of later date than these strata through which they pass; but upon the Triassic beds, rest later rocks of the Cretaceous age, and these are nowhere cut by the dikes. Hence we conclude that they came to their place at some time between the Triassic and the Cretaceous periods.

CHAPTER XXII

LIFE DURING THE ARCHEAN AND PALEOZOIC TIMES

Archean Rocks. — In the Archean, conditions existed which cannot now be determined, for the rocks of that period, whatever their origin was, are now so altered and metamorphosed that they have very little to tell us of the story of the earth. These rocks are either igneous or metamorphic. Among the latter there is a noticeable difference between two groups, one, the lower, being extremely metamorphosed; the other, or upper series, being only partially changed. This difference in the rocks has given rise to the division of the Archean into two groups, the Huronian and the Laurentian.

Among the characteristic rocks of the Laurentian period are gneisses, schists, and certain plutonic igneous rocks, particularly the granites. There are also beds of iron, and other minerals and rocks in less abundance than those which are considered as characteristic. These ancient strata are complexly intermingled and folded, so that with all the study which has been given them, very little has been determined concerning their structure, and practically nothing as regards their origin.

In the upper series, or the Huronian, rocks are arranged in more distinct beds, and are much less folded and changed, so that in many cases distinct stratification may be seen, and the original nature of the rocks can be determined. Thus among the Huronian strata are found the common forms of lava, and more or less distinctly altered beds of sandstone, limestone, and shale, which by metamorphism have been transformed to quartzite, marble, and slate.

Life in the Archean. — With the dawning of the Paleozoic, the waters of the sea were peopled with animals and plants, living in great numbers and considerable variety. Although only the faintest traces of life have been found in the rocks of Archean age, there is every reason for believing that the ancestors of these Paleozoic creatures lived during the Archean time. Very careful search has been made for records of this ancient life, with almost no success.

Some geologists believe that the beds of limestone and graphite, which occur among these ancient rocks, are indications of the presence of life when they were deposited. It is to be said, however, that while plants can be changed to coal and then to graphite, and while shell-bearing animals may construct beds of limestone, there are other ways in which both graphite and limestone may be formed. Hence the mere finding of these substances among the Archean rocks, is no proof of the existence of life in that period.

The belief in evolution makes it necessary to assume that the Paleozoic animals had ancestors in pre-Paleozoic times; and there is really some proof that life did exist then. Traces of what appear to be low types of animals have been discovered; but some of these, particularly the Eozoon, which was believed to represent the earliest form of life, are thought by some scientists to be nothing but a peculiar form of mineral.

Hence the question of the dawn of life, and the nature of the Archean animals, cannot even be conjectured. We have no doubt that life existed, and probably in considerable variety; but the changes to which these rocks have been subjected have so metamorphosed them, that all signs of fossils have been destroyed. It is possible also, that the earliest animals had no durable shells to leave, but were soft-bodied creatures which left little impression on the ocean rock.

Paleozoic Life

Sedimentary Strata. — Above the Archean, the rocks, although frequently crossed by igneous masses, and in some places changed by metamorphism, may be said to be typically sedimentary beds. By their characteristic composition and structure, they show their origin as deposits in water. Limestone strata, similar to those now being formed by the animals of the coral reefs of mid-ocean, are found embedded with shales and other forms of sedimentary rock. Ancient beds of sand and pebbles are present in many parts of the crust; and during all the ages since the Archean, these have been laid down, one layer on another, just as they are now gathering in the ocean.

These beds, originally deposited in a horizontal position on the shores and the bottom of the ocean, are now found in many places raised above the sea-level. Oftentimes they are still in a horizontal condition, although in many parts of the world, particularly among mountains, they are tilted and intricately folded. This change of position among the rocks of mountains has in many places, as for instance in New England, so altered or metamorphosed the sedimentary strata, that they have reached the

condition of schists, and even of gneisses, which closely resemble the rocks of the Archean. In fact, because of this resemblance, the strata of many parts of New England were for a long time classified as Archean, though they are now known to have been formed as sediments in the Paleozoic ocean.

The sedimentary beds of the more recent ages, more and more nearly approach the condition of the strata that are now being deposited in the ocean. Indeed, as a general statement it may be said, that the strata of the later ages are less and less solidified. There is every gradation between the extremely dense and hard sandstone of the early Paleozoic time, and the unsolidified sand of the modern beach.

Cambrian Organisms. — Something of the same sort as that just described for the Archean, applies to the Cambrian, the first of the Paleozoic ages. These rocks, the most ancient of the sedimentary strata, have been most subjected to changes; and hence many fossils that were originally preserved in them have in large measure been destroyed. Notwithstanding this, the Cambrian strata have furnished us with many different species of animals. It is possible that some plants and animals may have dwelt upon the land, but if so, they have failed to leave us a record of their existence.

Seaweeds are the only plants found fossil in the Cambrian rocks. The animals are all invertebrates, but not of extremely low forms. Corals, not unlike those of the present, lived in great numbers; and shell-fish, similar to some forms still existing, crawled over the ocean bed or burrowed in the mud. The two most

characteristic groups of Cambrian fossils are the *trilobites* (Plate 17) and the *brachiopods*. Of these, the former have since become extinct, and hence are not represented in the modern ocean; but the latter, although greatly reduced in numbers and variety, are still found in various parts of the sea. It is impossible to predict what the ancestry of these creatures was.

Life in the Ordovician. — During the next age, the Ordovician, or Lower Silurian, the life characteristics are very similar to those of the Cambrian. In this period the trilobites attained their greatest development; but after the Ordovician, these interesting creatures began to decline in numbers and variety, until their final extinction near the close of the Paleozoic. Brachiopods (Fig. 235) have also developed extensively, but have not yet reached their height of development.

While the Cambrian animal life of the sea is exclusively that of invertebrates, recent discoveries in Colorado possibly indicate that the higher forms of vertebrate life began to compete with invertebrates for dominion in the Ordovician sea. Fossils of true fishes are reported from the Ordovician rocks of Colorado; but this discovery is not universally accepted, and there is still doubt whether fishes really did appear before the next period, the Silurian.

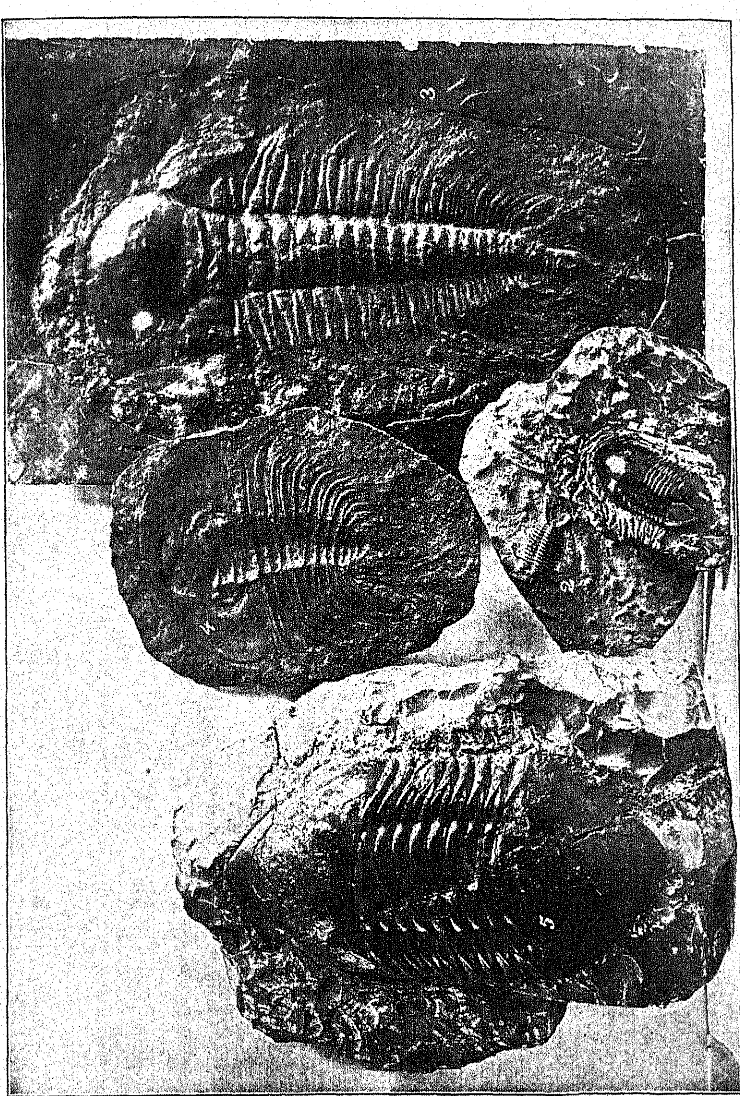


PLATE 17.

A group of Cambrian and Ordovician trilobites.
(1 and 5, Asaphus gigas from Trenton; 2, Ceraurus pleurexanthemus from Trenton; 3, Paradoxides harlani; 4, Olenellus thompsani from Cambrian.)

In one important respect the life of the Ordovician certainly differs from that of the Cambrian. Records of land life, both of plants and animals, are found preserved in these ancient strata. The plants are all of low forms, and the animals are of types lower than the insects. Nothing higher than this is known from the rocks of this time.

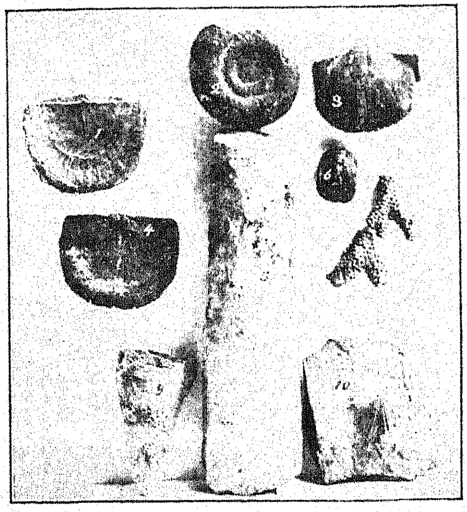


FIG. 235.

A group of Ordovician fossils. 1, 3, 4, 6, and 10, brachiopods; 2 and 5, cephalopods; 7, 8, and 9, corals.
(1, Strophomena alternata; 2, Trocholites ammonius; 3, Orthis sinuata; 4, Strophomena alternata; 5, Orthoceras amplicameratum; 6, Lingula quadrata; 7 and 8, Chaetetes dalei; 9, A cup coral; 10, Orthis lyrix.)

Silurian Life. — In the Silurian great progress in the history of life on the globe is made. The trilobites of the ocean, which were dominant in the Cambrian and Ordovician times, have diminished very decidedly; but the brachiopods and corals have continued to increase in importance and variety, and *crinoids* or sea-lilies have developed remarkably (Fig. 241). These beautiful

forms of marine life, which were so abundant in the Paleozoic seas, have continued to decrease since then, until at the present time they are rare in the ocean, and in their perfect development are mostly confined to the deep sea.

Another type of ocean invertebrate, which had some importance in the preceding ages, and became especially prominent in the Silurian, is that of the cephalopods (Figs. 235 (2 and 5) and 238). In the Paleozoic time these creatures were mainly represented by forms which dwelt in long and straight shells, which they constructed. Later, during the Mesozoic time, the cephalopods were dwellers in coiled shells, or else were creatures without a shell (Figs. 247 and 248).

These creatures still live in the modern ocean, where they are represented by the squid, cuttle-fish, and devil-fish, which are types that have lost the shell, and also by the nautilus and argonaut, which are forms that have retained the coiled shell. The development of variations in the shells and skeletons of these animals, has been most interesting. Indeed, it forms one of the best proofs of evolution which is furnished by the fossil record of animal life.

From the Silurian rocks is found the first definite record of the existence of true fishes upon the earth. These are found as fossils in considerable numbers among the strata of this age; and they present such variety and high development, that it seems difficult to believe that they really first appeared upon the earth

in this complete form. According to the theory of evolution, which receives so much support from the life record in the rocks, there should have been ancestors of less complex structure. Possibly the progenitors of these fishes had no true bones or scales which could be preserved in the rocks, and hence have left us no record of their existence.

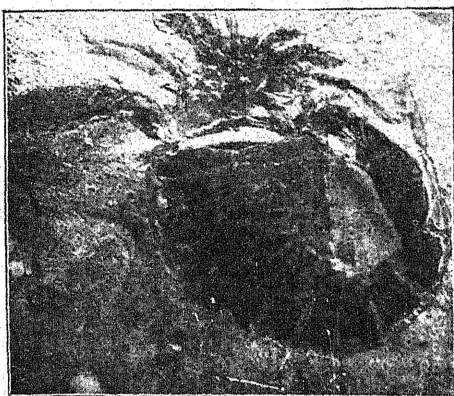


FIG. 236.

A crustacean from the Silurian beds. (Eurypterus lacustris.)

The types of Paleozoic fishes are quite different from those of the present time, although some shark-like forms then lived. Most of the Silurian fishes were covered with an armor of plate-like scales, so that they are graphically called mail-coated fishes (Fig. 239). Among the modern species, the sturgeon is the best-known representative of mail-clad fishes.

Considerable development of life is noticed on the land, although none of the higher groups of animals or plants have yet appeared. The plants have not left us a very perfect record of their existence, and

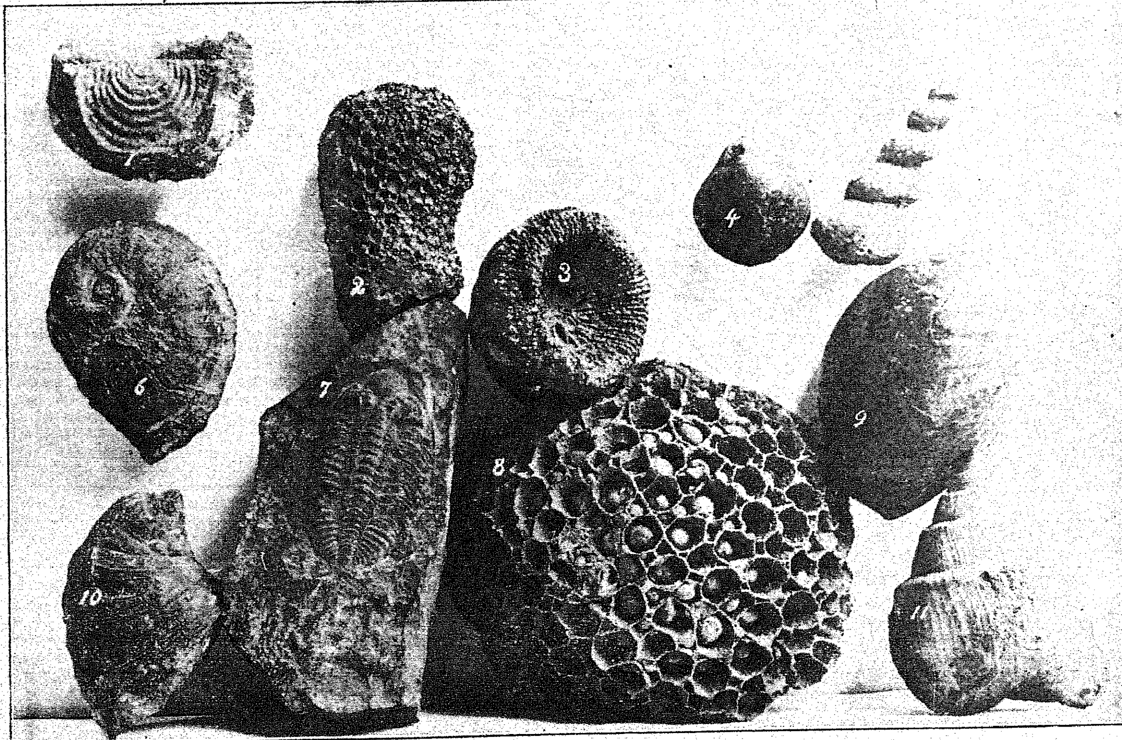


Plate 18.

A group of Devonian fossils. 1, 4, and 9, brachiopods; 2, 3, 8, and 10, corals; 5, 6, and 11, univalve mollusks; 7, trilobite. (1, Strophomena rugosa; 2, Favosites basalticus; 3 and 10, Cyathophyllum zenkeri; 4, Meristella nasuta; 5, Murchisonia boydi; 6, Platystoma lineatum; 7, Dalmanites selenurus; 8, Michelina convexa; 9, Amiphigenia elongata; 10, see 3; 11, Macrochilina arculatus.)

those that are found are of lower orders. The land animals are insects of low types, mainly allied to the group of cockroaches, which are the most ancient of insects. Scorpions are also present as fossils in the Silurian rocks.

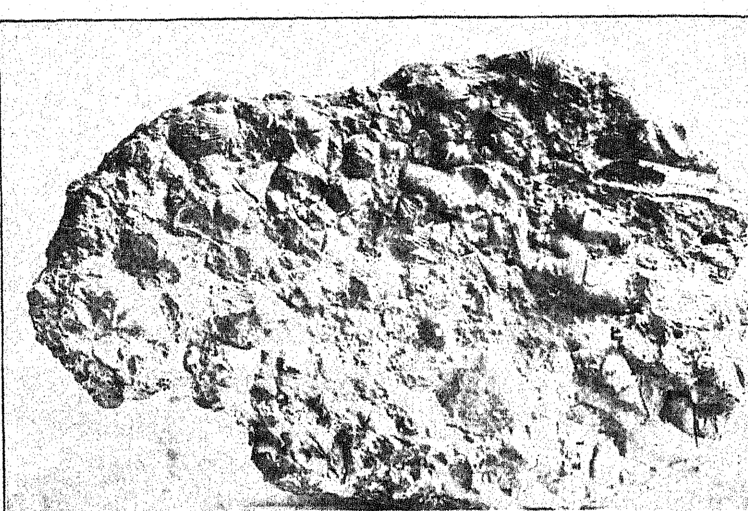


FIG. 237.

A slab containing many Devonian brachiopods.

Devonian Life. — In the Devonian, life progressed along several important lines. There is very little difference between the Devonian marine invertebrates and those of the preceding Silurian. Trilobites are slightly diminished in number and variety, while brachiopods have actually increased (Fig. 237). These interesting

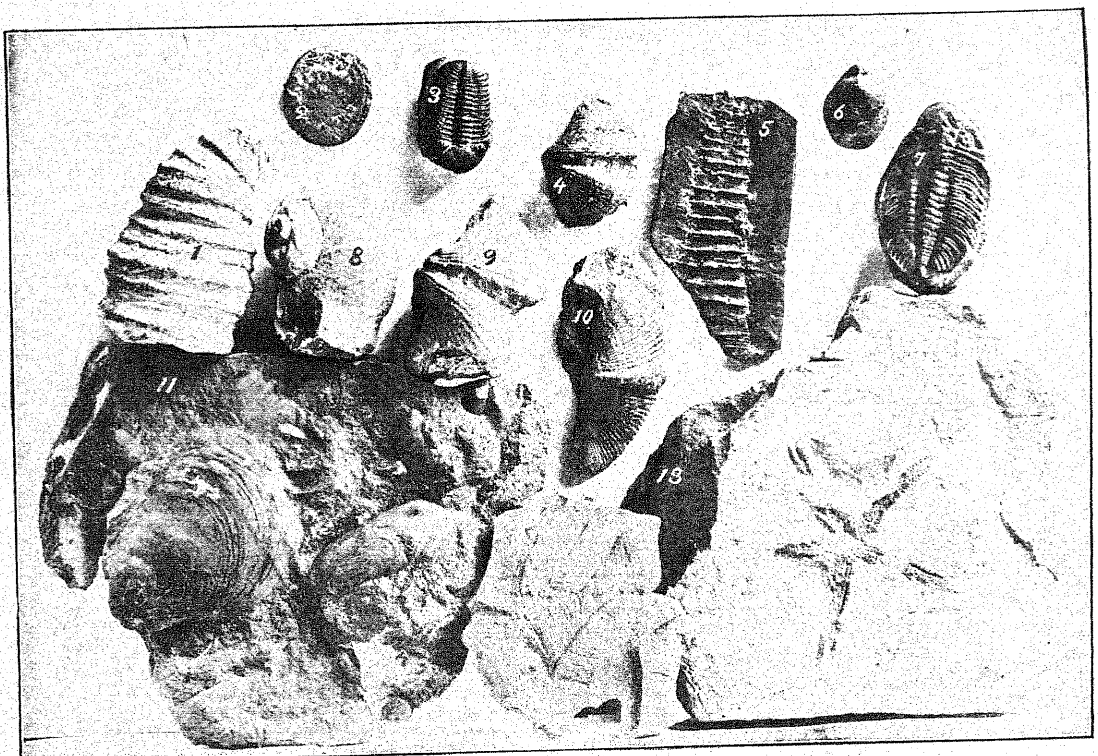


PLATE 19.

A group of Devonian fossils. 1, coral; 2, 4, 6, 9, and 10, brachiopods; 3 and 7, trilobites; 5, cephalopod; 8, univalve mollusk; 11, bivalve mollusks; 12, plant; 13, starfish.

(1, Heliophyllum halli; 2, Orthis penelope; 3, Phacops rana; 4, Spirifer medialis; 5, Orthoceras crotalum; 6, Cryptonella ludora; 7, Asaphus caudatus; 8, Pleurotomaria lucina; 9, Spirifer granuliferus; 10, Spirifer marcyi; 11, Glyptodesma erectum; 12, Ptilophyton vanuxemi; 13, a starfish.)

animals reach their culmination of development in this period, and have progressively declined ever since. There is also a development of the cephalopod group

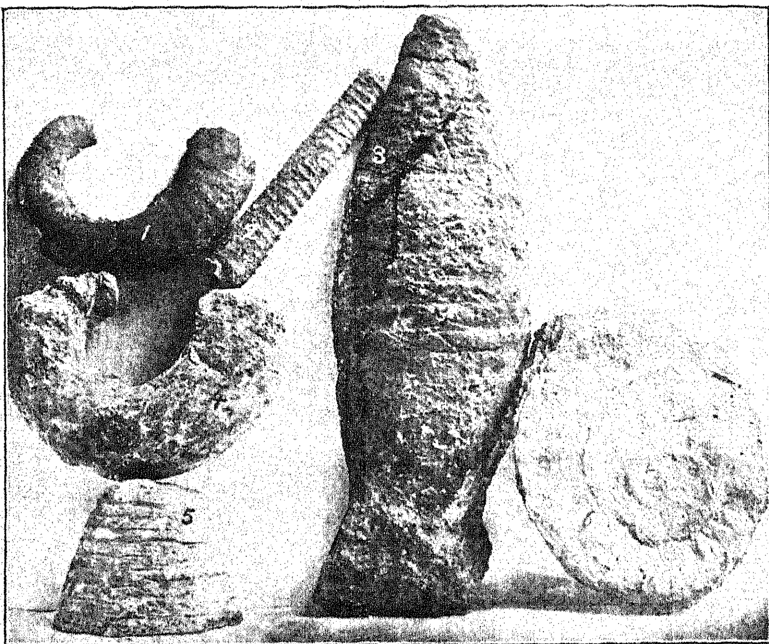


Fig. 238.

A group of Devonian cephalopods.
(1, Gyroceras validum; 2, Orthoceras thoas; 3, Gomphoceras; 4, Cyrtoceras; 5, Cyrtoceras lineatus; 6, Cyrtoceras undulatum.)

(Fig. 238), and an increase in the importance of reef-building corals.

However, it is among the true fishes that the greatest progress is made. The Devonian has been called the

age of fishes, not with the idea of asserting that those were the only animals, but merely that the most noticeable creatures were true fishes. They were, however, not like the food fishes of to-day, which are so well known in our streams, lakes, and oceans, but rather mail-clad forms (Fig. 239), and species like the sharks.

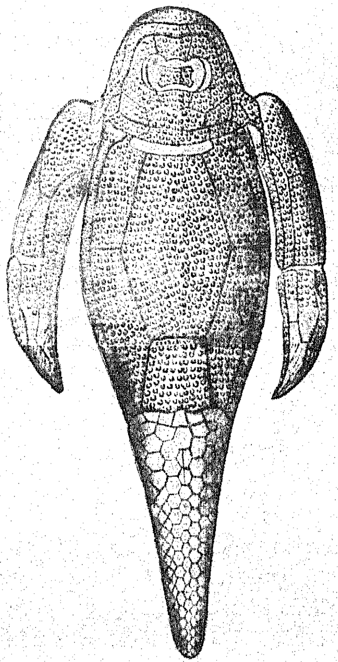


FIG. 239.
A Devonian fish (Pterichthys milleri, after Zittel).

While the record of vegetation in this period is not nearly so marked as in the Carboniferous, there is little reason for believing that the Devonian plant-life was sparse. In many places, where favorable conditions for the preservation of plant remains were present, we have extensive accumulations of these fossils. The plants of this time were strange in aspect, and not like those of the present. There were, for instance, no flowering plants, but the land was clothed with unique forests of ferns and other low types, developed to a great size.

Insects, which had appeared in the preceding ages,

were now developed in greater variety. Flying insects appeared (chiefly Orthoptera and Neuroptera), and some of them were of great size, having a spread of wings of one or two feet. Among the Devonian insects there was a notable absence of those interesting forms of bees, ants, butterflies, etc., which are now so abundant. These creatures, many of which depend upon plants and flowers for their existence, could not develop until vegetation had attained a sufficiently high character for their existence. The evolution of plants and insects has been continued side by side.

In the rocks of this and other ages, there are deposits of natural gas and oil, or petroleum, which owe their origin to the existence of animal and plant life upon the globe during past ages. The remains of these organisms accumulated among the rocks that were deposited in the seas or lakes, and in the course of ages, by slow distillation, the carbon and hydrogen of their bodies have in part been accumulated in the form of hydrocarbons, either of the gaseous or liquid kind. Wherever this decay of organic life is in progress, hydrocarbons are produced. This is well illustrated in the marsh gas which rises from the decay of vegetation in swampy places. Commonly the decay product escapes into the air, and hence is lost to man. But under some conditions, the hydrocarbons are allowed to accumulate in basins, some of which have since been pierced by wells.

The most favorable condition is a reservoir of porous rock capped by an impervious layer. The gases and liquids, derived from the distillation of the organic remains, rise into the porous rock and are prevented from escaping by the dense layer above. When this natural reservoir is pierced by a well, the pressure of the rock and gas, forces the substance to the surface.

Carboniferous Life. — Nothing new is noticed, in a large way, concerning the marine invertebrate life of the Carboniferous time, though the trilobites and brachiopods continued to decrease. A rather remarkable development of those beautiful creatures, the

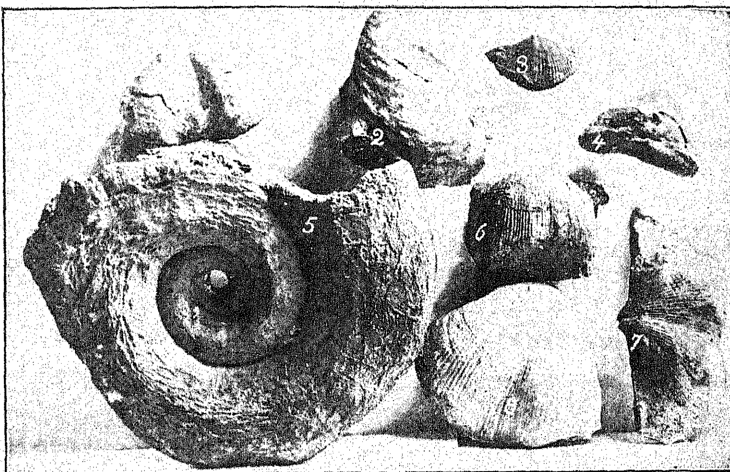


Fig. 240.

A group of Carboniferous fossils. 1, 3, 4, 6, 7, and 8, brachiopods; 2, bivalve mollusk; 5, cephalopod.

(1, Spirifer neglectus; 2, Inoceramus pseudomytiloides; 3, Spirifer forbesi; 4, Spirifer grimesi; 5, Nautilus; 6, Productus semireticulatus; 7, Spirifer logani; 8, Rhynchonella acuminata.)

sea-lilies, or crinoids, is noticed in the earlier part of this period (Fig. 241 and Plate 19). After this time they began to decline, until at present very few species are left in the ocean. The fishes were similar to those of the Devonian time.

It is in the land life that the greatest progress is noted. Here for the first time are found extensive records of plant life (Figs. 242 and 243). The conditions of the Carboniferous were unusually favorable for the preservation of these records. Extensive swamps bor-

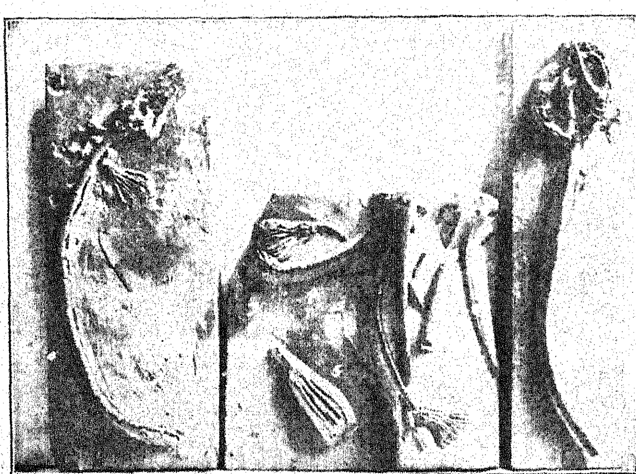


FIG. 241.

A group of Carboniferous crinoids.
(1, Cyathocrinus lyoni; 2, 3, 4, and 5, Scaphiocrinus aequalis; 6, Poteriocrinus decadactylus; 7, Onychocrinus exculptus.)

dered the land, and upon these, plants grew and died, and were later buried and preserved (p. 460) Many kinds of vegetation now extinct, and many now represented by small species, such as the fern, in that period grew to the height of large trees. The forests of the Carboniferous time did not resemble, in any detailed

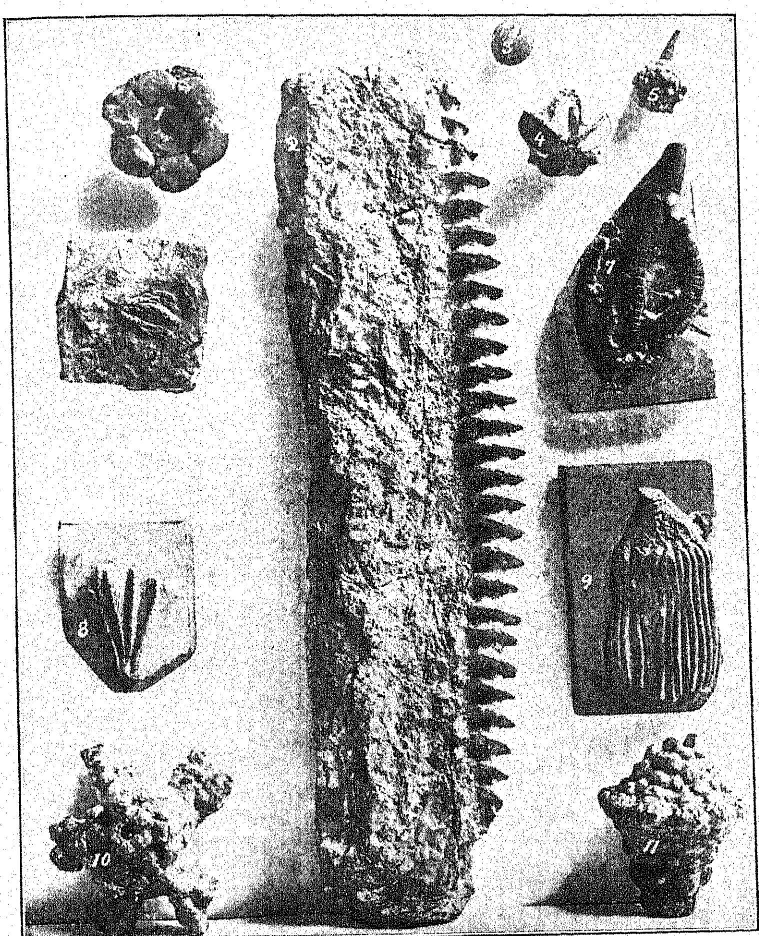


PLATE 20.

A group of Carboniferous crinoids.

(1, Megistocrinus evansi; 2, Archimedes reversa (a bryozoan); 3, Pentremites melo; 4, Pentremites cherokeus; 5, Actinocrinus unicornis; 6, Scaphiocrinus scoparius; 7, Onychocrinus exculptus; 8, Poteriocrinus decadactylus; 9, Actinocrinus ramulosus; 10, Actinocrinus lowi; 11, Actinocrinus nashvillæ.

way, the forests with which we are now acquainted (Fig. 244).

Not only were the trees of the forest different, but no birds existed among them, and the hum of the familiar insects could not be heard. Some progress among the insects is noted, but there is a rather close

Fig. 242.

Group of Carboniferous plant fossils from near coal beds.
(1, Pecopteris miltoni (a fern); 2, Alethopteris serlii (a fern); 3, Lepidodendron clypeatum; 4, Sigillaria mammillaris.)

resemblance between the insect fossils of Devonian and Carboniferous times. Many more species and individuals have been discovered in the Carboniferous rocks, mainly because when the plants were preserved, the insects that lived upon and in them were also buried and handed down as fossils.

By evolutionary processes of development, the amphibia (the group to which the frogs belong) and reptiles appear to have developed from the Devonian fishes. At first they were water animals, breathing with gills, and in this respect they resembled the true fishes.

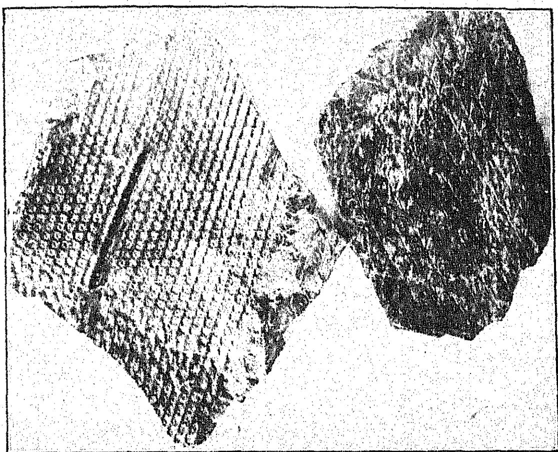


FIG. 243.

Carboniferous plants, — the bark of trees.

The amphibia first appear in the Carboniferous,[1] and there is a closer resemblance between the young of the present amphibia and the adults of these ancient species, than between the adults of the present and Carboniferous. The tadpole of to-day, which has gills, but no feet, probably resembles the earliest amphibia. In the process of development the tadpole form changes to that of the frog, which moves over the land and breathes air.

[1] Since this was written the discovery of amphibian footprints in the upper Devonian rocks of Pennsylvania is announced.

By the Permian, or upper stage of the Carboniferous, reptiles of rather high type have appeared upon the earth. It seems probable that the order of succession of development was from the fish to the amphibia, then to the reptile. What the ancestors of the true fishes

FIG. 244.

Ideal landscape of the Carboniferous period. (After Haushofer.)

were, cannot be predicted with certainty, but they are probably to be found among some of the invertebrates, perhaps the worms. The gap between the fishes and lower animals is a large one, and until we have learned more about this ancient life we can form no very satisfactory conclusion upon this interesting point.

With this period ends the Paleozoic, within which is preserved and recorded the *ancient history* of life upon the earth. By the close of the Paleozoic, many of the groups of plants and animals that now people the earth, have already come into existence. It may be said that the most typical Paleozoic animals are the marine invertebrates, but vertebrates of ancient types have developed. Neither fishes, amphibia, nor reptiles have close resemblance to the species of the same groups at present in existence. The same also is true of the land plants. They are of ancient forms in distinction from those of the present, which we call *modern*. The next period, the Mesozoic, is the time of the *Middle Ages* of life history. The close of the Paleozoic is the natural dividing line between two different epochs of time. Invertebrates predominate in the Paleozoic, but vertebrates take precedence in the next division. Even among the invertebrates there are differences of vast importance upon the two sides of this dividing line.

CHAPTER XXIII

LIFE DURING THE MESOZOIC AND CENOZOIC TIMES

Mesozoic Life.—The Mesozoic is divided into the Juratrias[1] and the Cretaceous. Although there are many differences in the life of the two parts of the Mesozoic, we may group the two periods together, in order to avoid repetition, and consider the history of development of the Juratrias and Cretaceous organisms at the same time.

Among the marine invertebrates, change is noticeable in the decrease of the brachiopods, and the nearly complete extinction of the trilobites, as well as a decrease in numbers and variety of the crinoids. Parallel with this is an increase in the relative importance of the cephalopod and lamellibranch (the bivalve shells) groups of the Mollusca (Fig. 246). These attained wonderful variety of form, and peopled the seas in great abundance. The univalve shells (gasteropods) were also of greater importance during this time than in previous ages. It is among the cephalopods, however, that the

[1] This is also often divided into Jurassic and Triassic.

most noticeable changes are seen (Figs. 247–249). The nautilus and ammonite groups of the Cephalopoda, with coiled shells, attained great variety. Besides these shell-bearing forms, some have become divested of external shell, and like the squid and devil-fish of the present sea, have a partial internal skeleton in place of the shell covering (Fig. 247 (2)).

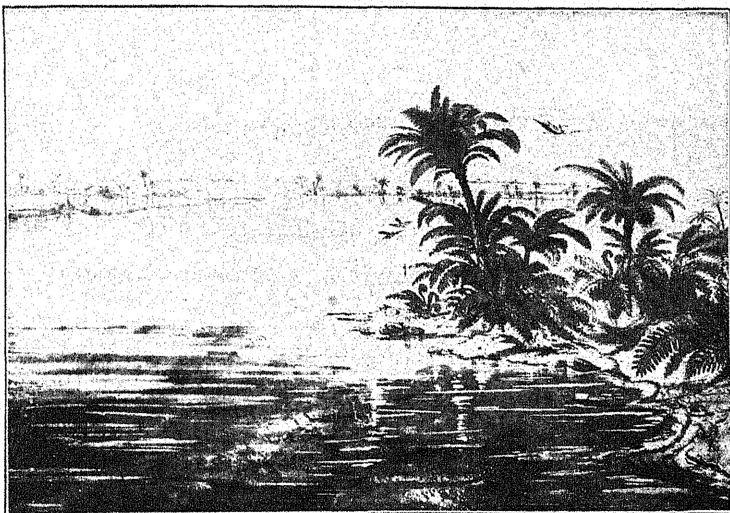


FIG. 245.

Ideal landscape of Jurassic period. (After Haushofer.)

In some parts of the world, entire beds of rock are made of the remains of molluscan shells. There are, for instance, in central Texas, Cretaceous strata composed almost entirely of oyster shells (Fig. 250); in fact, the oyster group of bivalve shells is one of the most characteristic of the Mesozoic time.

In England and France, as well as in Texas and Iowa, there are also beds of Cretaceous rock composed of extremely minute forms of life, producing the well-known *chalk*. These strata were formed in the deep sea of this period, by minute animals that swam at the surface, and upon death dropped to the bottom, forming an ooze quite like the Globigerina ooze (p. 257) now accumulating in the depths of the sea.

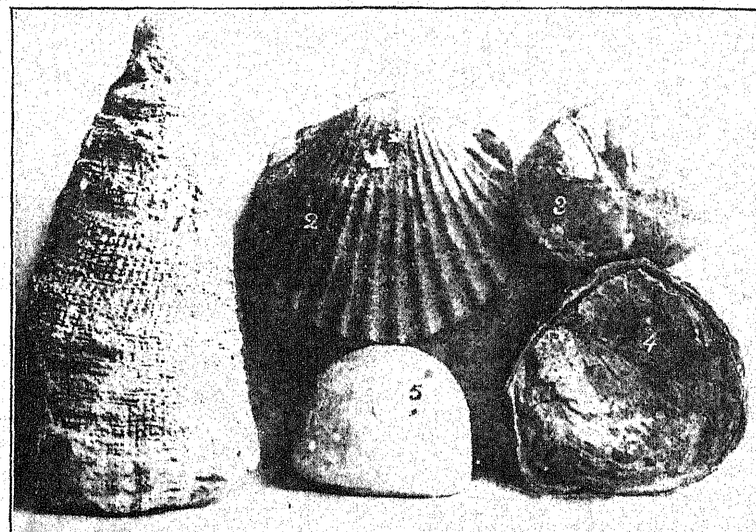


FIG. 246.

A group of Cretaceous fossils.
(1, Hippurites radiosa; 2, Pecten equivalvis; 3, Toxaster elegans; 4, Gryphea vesicularis (an oyster); 5, Ananchytes ovatus.)

A noticeable development is also seen in the fishes; but the characteristic Mesozoic fish is still of the ancient armored type, mentioned in the description of the Paleozoic life.

The amphibians, which began to be important in the Carboniferous, decrease during the Mesozoic, and their place is taken by reptiles, which have developed into extraordinary abundance, variety, and size. In fact, the Mesozoic has been called the *Age of Reptiles*. Immense

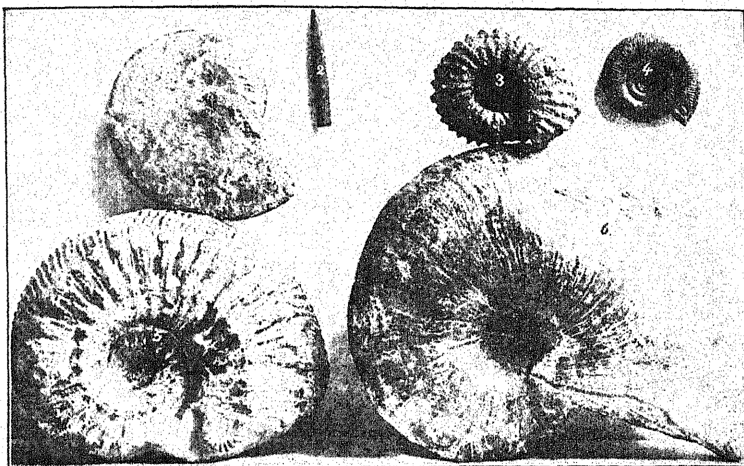


Fig. 247.

A group of Cretaceous cephalopods.
(1, Ammonites subradetus; Belemnites sp.; 3, Ammonites mammilatus; 4, Ammonites semicelatus; 5, Ammonites henleyi; 6, Nautilus semistriatus.)

land saurians (Dinosaurus, etc. (Fig. 251)), as large as our largest mammals, in fact in some cases even larger than the elephant, moved sluggishly over the land, some feeding upon plants, and even reaching into the branches of trees for their food, while others subsisted upon their fellow-creatures. In the sea, huge reptiles

(Ichthyosaurus, etc. (Fig. 252)) swam about in great numbers, and immense bat-like forms (Pterodactylus, etc. (Fig. 253)) flew through the air. In some places we still find the footprints of these various reptilian

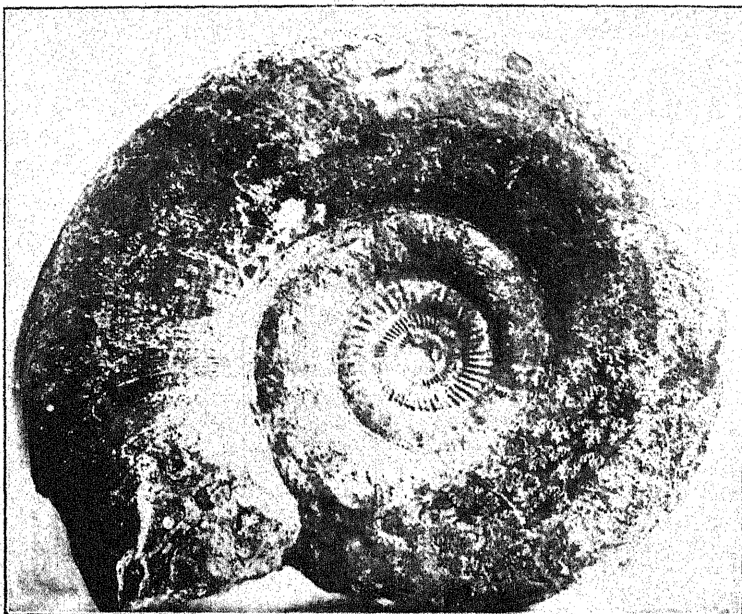


FIG. 248.

A Mesozoic cephalopod. (Ammonites subradiatus.)

types preserved in the rocks; and scales and other parts are sometimes preserved, so that there seems to have been a wonderful variety of reptile life.

Birds began to appear in the Mesozoic. These are evidently descendants of reptilian ancestors. Some of

them have teeth and other reptilian characteristics, (Figs. 254–256) so that one is very much in doubt whether they (such as the Archæopteryx (Fig. 255)) are really birds with teeth, or reptiles with feathers. They furnish one of the best illustrations of evolution so far found in the record of life preserved in the rock.

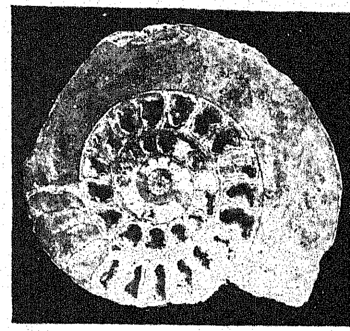


Fig. 249.

Section in the middle of Fig. 248, showing chambers of cephalopod shell, each occupied by the animal as it grew. Now partly filled with mineral substances.

Mammals of low types first appeared in the Juratrias time, and by the close of the Mesozoic, this group of animals is well represented upon the earth. In this country the earliest mammals have been found in the Triassic beds of North Carolina. They belong to the lower orders (Marsupials and Monotremes) of mammals, which are now represented on the earth only by a few species, of which the kangaroo and the duck-billed platypus of Australia are examples. While it is not certain what the ancestry of these ancient mammals is, there is some reason for thinking that they have descended from the Amphibia. The lowest forms of mammals lay eggs very much in the same way that these low vertebrates do.

By the close of the Cretaceous, land plants have begun to assume the characteristics of the present (Fig. 257). The ancient tree ferns have begun to disappear, and the forests are of palms, pines, and deciduous trees like those of the present. Among the deciduous trees there

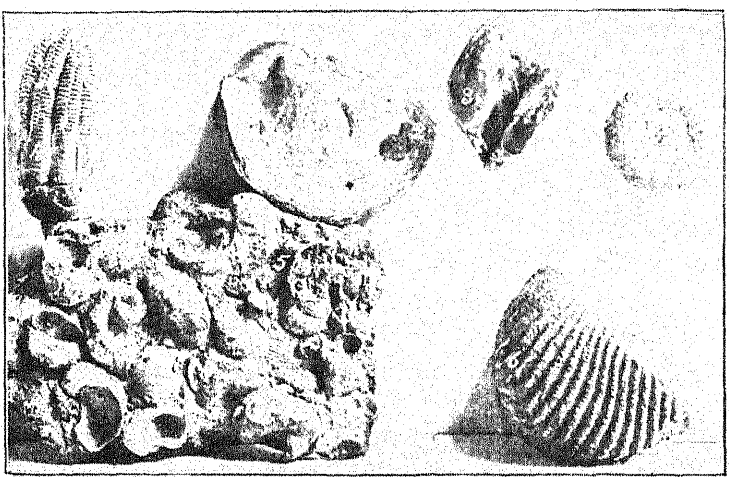


FIG. 250.

Group of Cretaceous fossils.
(1, Encrinus liliformis; 2, Exogyra matheromana; 3, Pugnellus densatus; 4, Cyphosoma texana; 5, Exogyra arietina (oysters); 6, Trigonia crenulata.)

are species of willow, maple, and other types now well known. Many of the common flowering plants also existed in this period, and the whole development of the flora was towards the conditions of the present. Little by little the ancient type of plant disappeared, as was the case also with the animals. With the develop-

ment of flowering plants there came a great increase in insect life, so that by the close of this period the various types of insects now known had appeared.

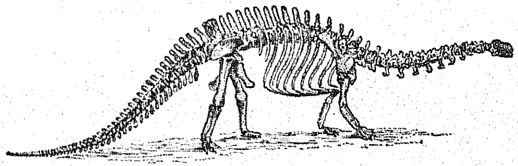


Fig. 251.

Skeleton of Brontosaurus. A Juratrias reptile.

Cenozoic Life. — In the Cenozoic, the forms of life, both on land and sea, began to closely resemble those which are now known. This was distinctly the *Modern Age* of life history on the earth. The illustrations

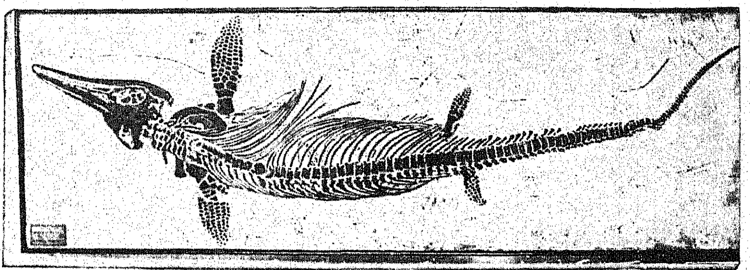


Fig. 252.

Ward's cast of skeleton of Ichthyosaurus; a Juratrias reptile.

(Plates 22 to 24, and Fig. 258) show that the invertebrate life was quite like that of the present ocean. On the land the most remarkable development is among the mammals, and this is very appropriately called the

Age of Mammals. The lower types, which began in the Mesozoic, little by little diminished in variety and

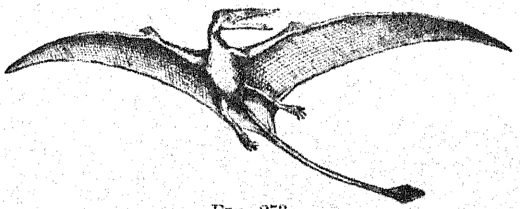


Fig. 253.
Marsh's restoration of flying reptile.

importance, and their place is taken by the higher forms of mammals. At first these were large species (Plate 21); but as time progressed, the size diminished, until at present large mammals are the exception. During the Tertiary, many species as large as the elephant were in existence.

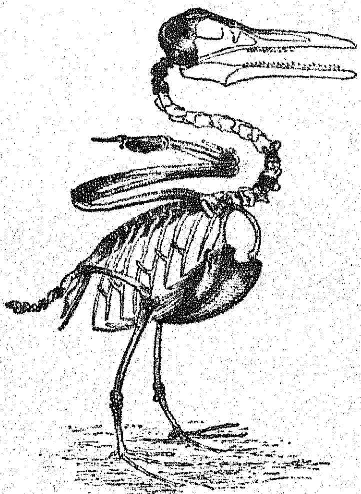


Fig. 254.
Ichthyornis victor. A bird with teeth.
(Cretaceous.)

If we could have had a view of the land during the mid-Tertiary time, we would have seen very little difference between the life of that period and the present. There would be many trees, flowers, insects, birds, and mammals which were strange to us, but the general

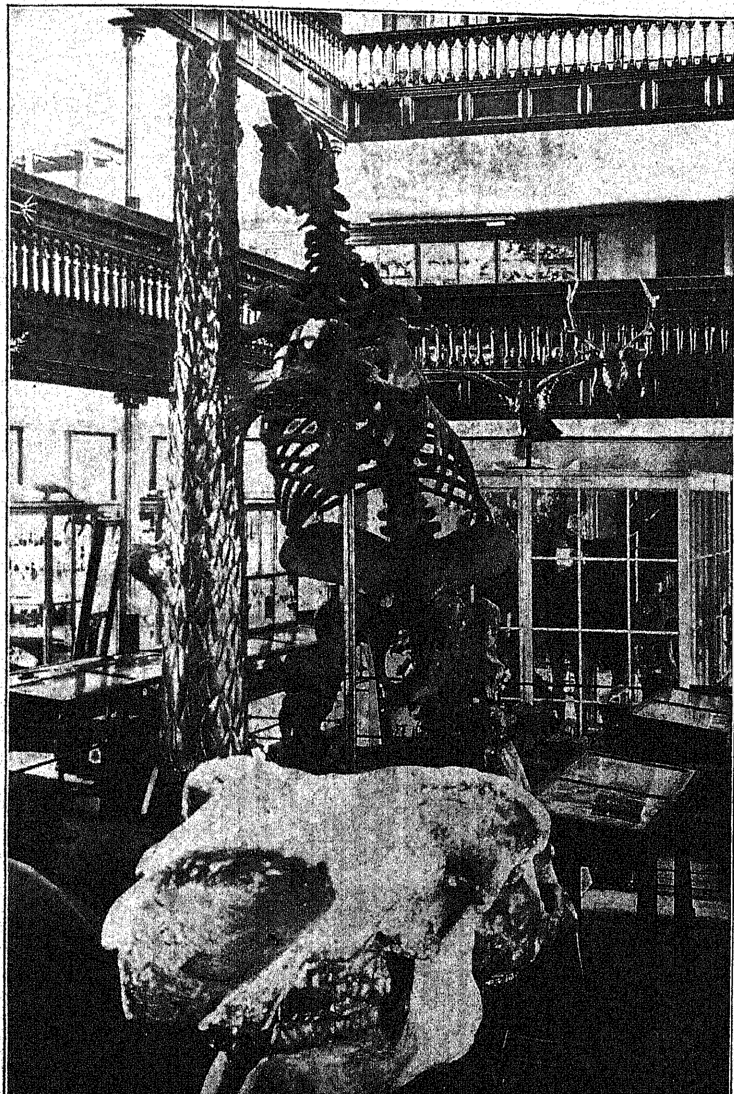


PLATE 21.

Megatherium; a gigantic Tertiary mammal. (Ward's cast.)

appearance of each of these groups would be quite like that of the present. The forests would have been found to consist of oak, pine, spruce, maple, etc.; many of the birds would have been songsters, and not the crude, reptilian forms of the Mesozoic; and many of the insects would have belonged to the types like the ant, butterfly, bee, etc.

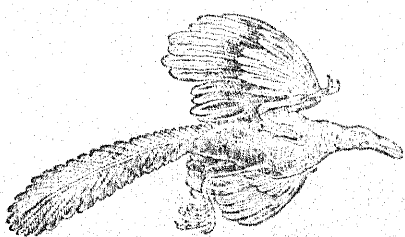


FIG. 255.
A restoration of Archaeopterix. A Juratrias reptilian bird. (After Owen.)

Little by little the strange and ancient species have disappeared (Fig. 260), and even since man came upon the earth, some of the old forms have been destroyed. The mastodon, a huge creature resembling the elephant, but bearing a fur, has disappeared since the coming of man. Various large and awkward birds have even disappeared within historic times. This is notably true in the case of some birds of New Zealand, and the great auk of the Labrador coast. Even now the agency of man is at work in the destruction of many mammals and birds, among the former notably the bison and elephant.

FIG. 256.
Hesperornis regalis. A bird with teeth. (Cretaceous.)

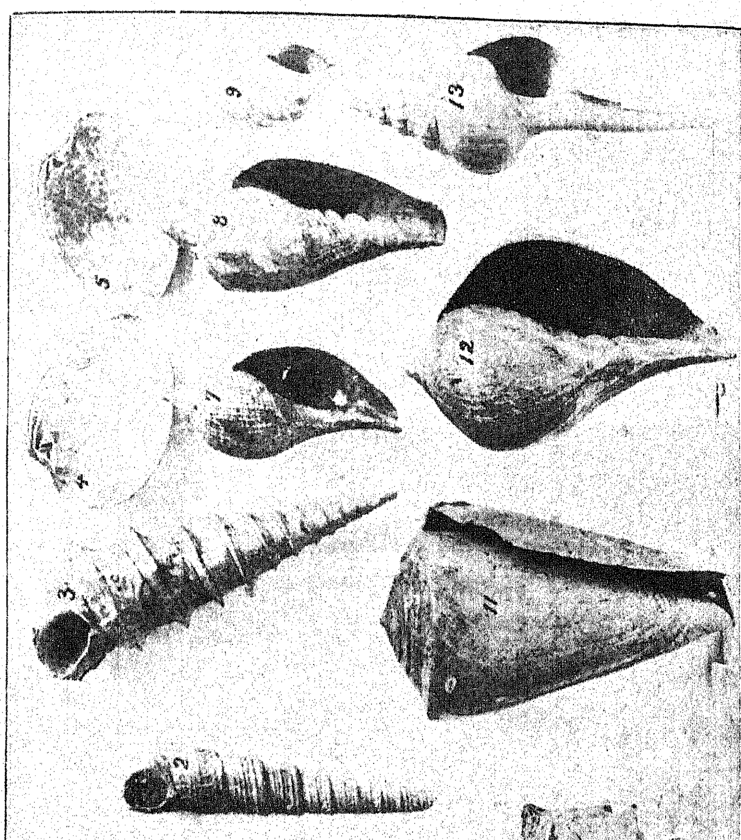


PLATE 22.

A group of Eocene fossils.

(1, Pseudoliva vetusta; 2, Turritella humerosa; 3, Turritella mortoni; 4 and 5, Cytherea æquorea; 6, Venericardia alticostata; 7, Pyrula penita; 8, Volutilithes sayanus; 9, Rostellaria velata; 10, Cornulina armigera; 11, Conus sauridens; 12, Caricella pyruloides; 13, Clavilithes pachyleurus.)

The crowning feature of the progress of life upon the globe, was the coming of man. How he came, by what ancestry, or by what means, it is impossible at present to say, nor can we state when he came. It is certain that man has lived upon the earth many thou-

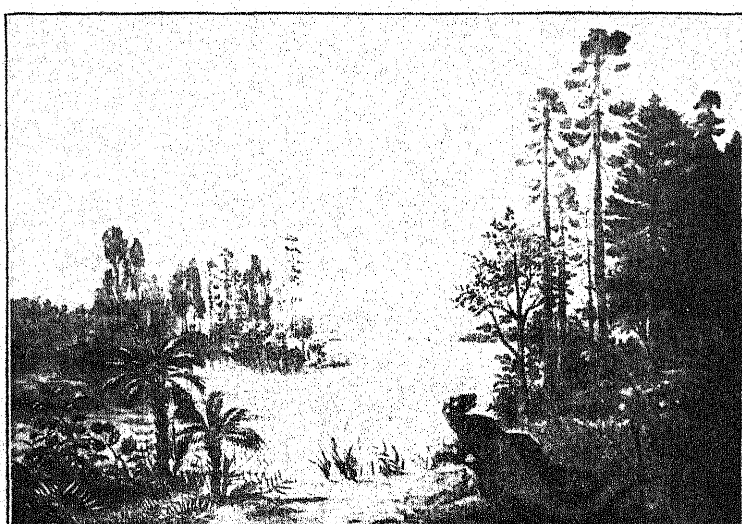


FIG. 257.
Ideal landscape of Cretaceous period. (After Haushofer.)

sands of years; and it is probable that his time of life is to be numbered in scores of thousands of years. There is good evidence that he lived as a contemporary of the glacial period, which involved northern Europe and America in an ice sheet, certainly many thousands of years ago. He also lived in association with types

of mammals, such as the cave-bear and mastodon, which have since become extinct.

While the point cannot be supported by definite proof,

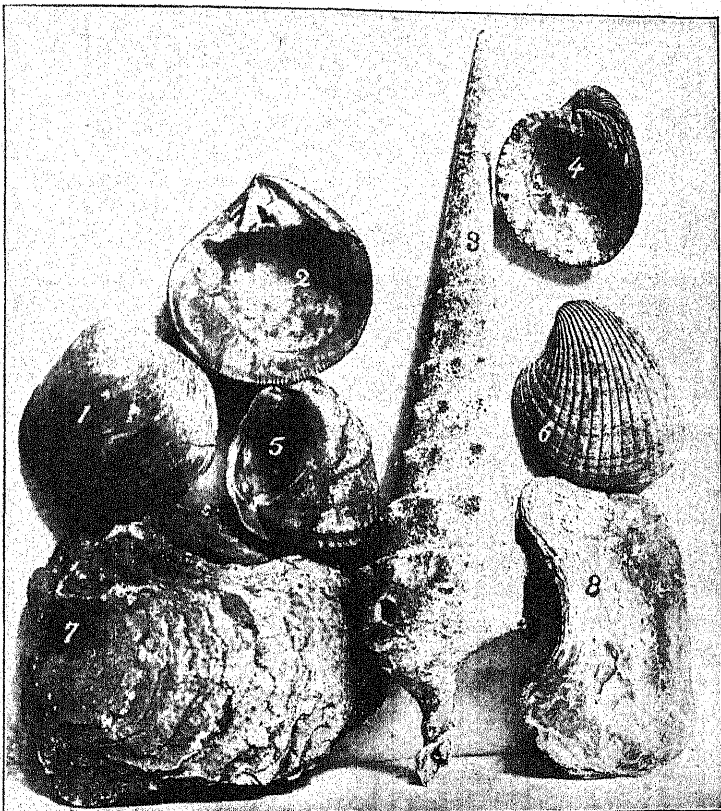


FIG. 258.

A group of Eocene fossils.
(1 and 2, Crassatella alta; 3, Cerithium giganteum; 4 and 6, Venericardia planicosta; 5, Lacinia alveata; 7 and 8, Ostrea sellæformis.)

PLATE 23.

A group of Neocene lamellibranchs from Virginia.

(1, Crassatella undulata; 2 and 3, Panopea americana; 4, Venus tridacnoides; 5 and 6, Pecten jeffersonius.)

PLATE 24.

A group of Neocene fossils.

(1 and 7, Chama corticosa; 2, Isocardia sp.; 3 and 4, Pectunculus subovatus; 5, Fusus parilis; 6, Dosinia acetabula.)

there are many who believe that the ancestry of man, like that of other creatures upon the earth, has been from some lower type; and that all life on the earth is an illustration of the law of progress which seems to be everywhere expressing itself. For some reason, variously explained, there has been an evolution among the lower forms of life, whose ultimate result has been higher development and more perfect adaptation to surroundings. In this progress some see merely the working of a blind law, while others find distinct evidence of supreme guidance. The belief in this evolution by no means necessitates abandonment of the belief in creation and Creator. To make the world and the life of the world ever better would certainly not be out of harmony with the belief in divine guidance of earthly matters.

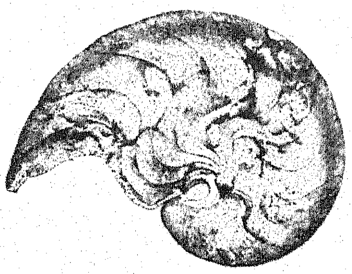


FIG. 259.
A Tertiary cephalopod. (Enclimatoceras ulrichi.)

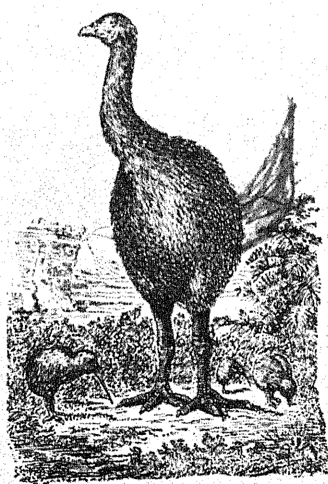


FIG. 260.
Dinornis; a Quaternary bird.

While evolution is as certainly proved for the lower forms of plants and animals as most scientific theories can be proved by man, with his limited capacities for observation and his preconceptions of logic, it cannot be said that the same is true for man. So far, the rocks have failed utterly to yield any positive proof that man is descended from lower animals. The most ancient skeletons that have been discovered, skeletons which have been buried five, ten, or perhaps even twenty thousand years, have perfectly developed skulls; and the skull is the most characteristic feature in man to distinguish him from the nearest animal, the ape. Hence, although the ancient men whose remains have been discovered were savages, and lived in the crudest way, they were thinking men with the brain well developed.

It would not be fair to leave this question here, however, for a discovery has recently been announced from Java, which may be the connecting link between man and his ancestors. This discovery is that of the skeleton of a man-like ape, or as some think, that of an ape-like man, in a stratum of rock, buried beneath a lava flow of a very ancient date. From this single discovery a general conclusion is not warranted, for it is by no means certain that this skeleton may not be that of some degenerate man. Some in fact have explained it as the skeleton of an idiot.

If the evolutionary theory for the origin of man is correct, then as explorations continue among the rocks of Tertiary age, we should find the remains of this missing link. The fact that we have not, by no means disproves the theory, but leaves it still a theory. No one has a right to anything more than an opinion upon the origin of man, so far as evidence from geology is concerned.

CHAPTER XXIV

ARCHEAN AND PALEOZOIC GEOGRAPHY OF THE UNITED STATES

A Speculation concerning the Earliest Earth History. — Since so little is known concerning the rocks of the Archean, and since it is not certain even what rocks belong to this period, it is difficult to say much about the conditions existing during this ancient time. Nor are we able to do more than to speculate with regard to the history of the earth before the Archean. Therefore if we would gain a glimpse of the conditions of these early times, we must resort to speculation. If we were studying the known history of man, we would naturally desire to know something with regard to his probably early history, before he made definite records of his doings. So in geology, it is interesting to speculate about the early development, before we commence to interpret the later and better known portions of this history. Such specu-

lation will do no harm, provided we bear in mind that it is mere *speculation*, and not *fact*, with which we are dealing.

The Nebular Hypothesis teaches that the earth was once a liquid sphere, and that it has now reached a stage in its development when the surface is cold and the interior heated. Provided this hypothesis is a true explanation of the origin of the earth's features, there must have been a time in its development when the liquid sphere became cold at the surface. So far as we have been able to discover, there is no record of this period among the rocks.

During the time when the surface of the earth, though covered with a thin solid crust, was still very much heated, it must have been enveloped by an atmosphere which contained not only all the gases now found in it, but also the waters of the ocean, and probably some substances which now exist on the surface in solid form. So during this period the atmosphere was very different from that of the present.

In time, still following our speculation, the earth cooled so far that the vapor of the air began to condense and to cover the surface of the earth with a film of water. At first this heated rain, upon reaching the hot crust, would be evaporated and returned to the air in the form of steam, and this process of heated rain, changed back to vapor, would be passed through again and again. So for a time the surface received frequent baths of highly heated water; and this had not only the power of erosion, which water naturally possesses, but also the ability to do important chemical work. This rain would obtain from the impure atmosphere many substances which increased its effectiveness in solution and change of minerals. When finally the waters of the atmosphere changed from the condition of vapor to that of liquid, and found relatively permanent rest in the form of oceans, it was still heated water, and in it was contained much rock matter in solution. As the warmth of the ocean decreased, some of these substances were

of necessity deposited, just as salt is precipitated from a solution in hot water when this is cooled.

In this ancient period, lava flows were more abundant than now, for the crust separating the earth's surface from the heated (then liquid) interior, was much thinner than at present. This nearness of heated and even molten rock beneath the crust, allowed the latter to fold and move with greater activity than is possible in its present rigid state. It is also probable that the temperature of the sun was different from the present, probably being higher. Astronomers suggest also that the tides of early times were more powerful, and the days shorter, so that the earth was then a very different sphere from now.

Perhaps in this early time of greater activity of all the agencies of air, water, and even the earth itself, the Archean rocks were formed. It was formerly thought that these really represented the ancient and first crust of the earth, and though many now question this hypothesis, it cannot even yet be considered to be disproved. If our speculation concerning the origin of the earth from a liquid condition is correct, there must have been a time in the earth's history when rocks quite like those of the Archean were formed. These would be somewhat like the igneous rocks; but with the ease of movement of the crust, it is probable that they would be easily folded and contorted. At the time when the hot waters were falling to the surface, their great chemical activity and erosive power would cause the accumulation of beds in the ocean, which, heated by lava intrusions and flows, and by the liquid rock beneath the crust, would bear very little resemblance to the sediment deposits that are now being accumulated.

Up to this time no life could exist upon the earth, because the temperature of land and water would be above that at which life, as we know it, could exist; but the time came when there were conditions favorable to life. At first only low creatures could exist in the hot and impure waters; and then began that wonderful series of changes and progressions of animals and plants, which is revealed in the later rocks, and which has culminated

in a world peopled by man. This change toward present conditions involved the purification of both air and water of noxious gases and other substances unfavorable to the existence of life.

With the coming of organisms in the clearer waters of the globe, there also appeared more quiet conditions of air and water action, and less activity within the earth itself, which was now less highly heated near the surface. It is only after the introduction of these new conditions of air and water action, and after life had taken possession of the waters of the ocean, and part of the land, that the geological record becomes really readable.

This which has preceded is speculation; that which follows is mainly fact obtained from the record of the rocks. It is possible that the ancient history of the earth has been quite different from that just stated; but it is probable that the later history, as stated in the following pages, will not be changed in its essential principles.

Archean Geography. — At the close of the Archean, the United States was partly above the sea and partly beneath it (Fig. 261). There were three distinct land areas. One, in the east, stretched from north of New England as far south as Georgia, and perhaps beyond. The second included the greater part of Canada, extending from the Arctic down to the United States boundary, which it crossed in at least two places, one in the Adirondack region, the other near Lake Superior. The third area was in the Far West, along the ranges of mountains which later became the Cordilleras.

The sea occupied a part, and at times possibly all of the area of the Mississippi valley between these three land boundaries. It is certain that a few islands existed in this sea during a part of its existence. One of these was in central Missouri, another in central Texas. Since the greater part of the Mississippi valley is occupied by

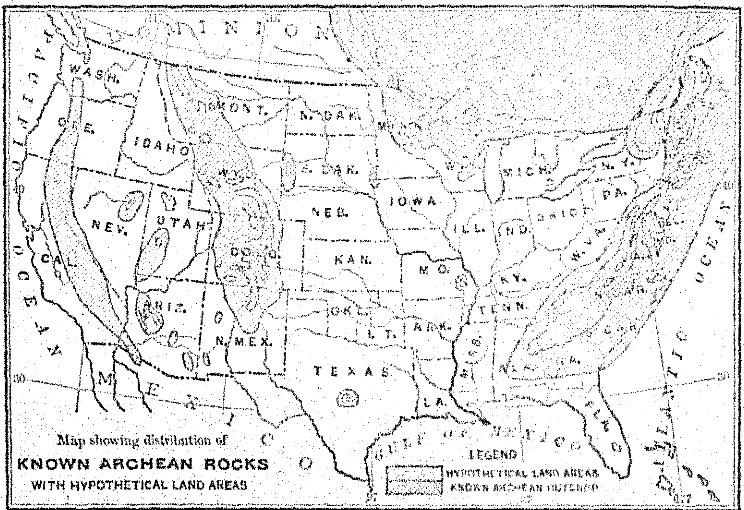


FIG. 261.

rocks of later age than the Archean, the record of the history of this ancient period in this part of the country is buried too deeply to be read at present.

Concerning the Canadian and western lands little is now known, for geological exploration has not been carried on extensively there We do know that even then these were mountainous lands.

The eastern land was also a mountainous one, with chains extending approximately parallel with those of the present Appalachian chains; but this mountain range was east of the Appalachians, and their site was then covered by water. Before the beginning of the Cambrian, the ancient eastern mountains, which had once risen into the form of extremely lofty ranges, were worn down to a series of hills, not unlike those of New England. Again and again, in later times, mountain folding has occurred in this eastern range, and between the times of folding there were periods of destruction by denudation.

Cambrian Geography. — Although we are able to form a somewhat clearer idea of the physical geography of this period than we were of the Archean, our knowledge of it is nevertheless very limited. We are able to say very little about the climate of the Cambrian, for the life record that has been found is that of ocean animals, which give us no clue concerning the conditions upon the land.

For a time, and possibly throughout the entire period, the site of the great Mississippi valley was occupied by the sea; and so it remained throughout nearly the entire Paleozoic era. The Adirondacks rose as an island in this ocean, and the ancient Cambrian beaches are now revealed at their base. While it is not possible to trace the old shore-line in accu-

rate detail, beaches found every here and there show that the coast-line of the eastern margin of the interior sea stretched along the line now occupied by the eastern part of the Appalachians. This great series of Cambrian beaches extended from New England at least as far south as Georgia.

There was apparently an extensive land area in Canada, and the site of some of the Archean mountains of the west was still occupied by land, though a part of this western region was beneath the sea. We know this because rocks formed in the ocean of that time have been found built into the mountains. From these facts it seems probable that the site of the Cordilleras was an archipelago, possibly like the East Indies of to-day.

During this period the ancient eastern mountains were subjected to re-elevation; and from New England to Virginia, and probably further, volcanoes existed, sending lava flows and ash eruptions to the surface. Volcanic rocks have also been found in the Cambrian of the Lake Superior district, so that we know that these two regions, now free from volcanoes, were once the seat of active eruptions.

The operation of the agencies of air and ocean seems to have been quite like that of the present, although it is possible that the air was still charged with different substances from those composing the atmosphere of to-day. Since much carbonic acid

has united with other elements, and entered into the rocks of later times, and since much oxygen has also entered into combination in the earth's crust, it seems probable that the air of the Cambrian time was charged with these two gases in very much greater percentage than we now find. It is possible also that the ocean was more impure, and that some of the beds of limestone which were formed in the Paleozoic seas, represent precipitations of these minerals from solution in the sea water.

Ordovician Geography. — Both the Cambrian and Ordovician rocks of the east show such vast changes in many places, that little can be told concerning the conditions under which they were accumulated. There has been much metamorphism in these ancient strata, so that sandstones have been transformed to quartzites, limestones to marbles, and shales to slates. In fact, in some parts of New England, the alteration has passed so far that schists and gneisses have been formed out of these Paleozoic sediments.

The inland sea covered approximately the same area as that of the Cambrian; and until the close of the Ordovician, the geographic conditions of the country appear to have been but a continuation of those of the preceding period.

The close of the Ordovician was marked by a mighty uplift along the chain of eastern mountains. By the beginning of this period, the Archean chains had no doubt been worn in places to the condition of low hills, like those now found in eastern Mary-

land and Pennsylvania, or to the condition of low mountain ranges such as those now seen in New England. This destruction of the mountains continued throughout the greater part of Ordovician times, until they were probably quite reduced in elevation and subdued in outline. Then came the mountain development which affected New England, certainly as far east as the Connecticut River, and possibly even as far as our present coast-line. How far south and north of this the mountain growth extended, is not yet determined, but the folding was widespread.

We know that this mountain formation occurred at this period, because the Ordovician rocks, formed distinctly in the sea, are now extensively folded and metamorphosed, while the strata of the next succeeding period, also deposited in the sea, are not so disturbed. These later rocks rest unconformably upon the tilted edges of the mountain strata. Hence between the time of formation of the Ordovician and the deposit of the Silurian rocks, the former were uplifted and folded.

The growth of this mountain range was intense, and the chain of peaks reached to great heights. At present these mountains have been so worn and denuded by the removal of their upper portions, that they are dissected so as to reveal even their very roots. The Green Mountains, Berkshire Hills, Taconic ranges, the mountains of western Connecticut, and the rocks upon which the city of New York is built, represent the roots of parts of these ancient mountains.

We can hardly find a more impressive lesson than this, of the great changes taught by geological study. What a vast amount of time must have been required for the accumulation of the great deposits of the Cambrian and Ordovician strata, reaching a depth of several thousand feet! And then what immense time must have been needed to have uplifted these into the form of lofty mountains, and then for their extensive destruction and planing down almost to sea-level!

While this mountain folding was in progress in the east, there were apparently changes of great import in the west; but our studies of this region have not yet progressed far enough for any detailed statement of these changes.

At the same time as the formation of the mountains in the east, a gentle uplift of the bottom of the sea occurred on the site of the present states of Ohio, Kentucky, and Indiana, while a smaller one occurred in Tennessee. The former has been called the Cincinnati arch. This was not a really mountainous growth, but a broad uplift of a part of the ocean bottom, which reached above sea-level.

Silurian Geography. — This period and the succeeding, the Devonian, have been studied with great care in New York; and since this study has revealed the history of this part of the country, it will be stated in more detail than has been given to the preceding epochs. The changes recorded in the Silurian strata

are probably similar to those of other parts of the country, and of other ages; but they have been worked out so satisfactorily that they serve as a better illustration than any other district which we know in America.

The state of New York during the Silurian was occupied by sea, excepting in the eastern part along the bases of the mountains that were developed at the close of the Ordovician, and also in the Adirondack region, which rose out of the sea as a mountainous mass. The coast-line of this sea was therefore in the eastern part of the state, and the waters deepened toward the west. Therefore, since sediments are coarser near the shore than at a distance from it, the rocks of this age vary in coarseness from the shore into the deeper parts in the western portion of the state.

The lower strata of the Silurian (known as the Oneida) are conglomerates in the east, grading to sandstone in the west (known in New York as Medina sandstone), and beyond this to shales. The conglomerate represents the ancient beach along the shores of the inland sea. At present it is found extending throughout the folds of the Appalachians, into which it has been built by mountain formation of a later period; for the site of the Appalachians was still sea during the Silurian time. Because of its great strength in resisting denudation, this consolidated beach, composed of quartz and other pebbles, cemented in a matrix of sand, now rises to form the crests of many of the Appalachian ranges. The conglomerate bed reaches the thickness of from five to eight hundred feet.

Above the Medina sandstone group is found a series of shale and limestone, known as the Clinton group in New York. These

beds extend from New York state southward to Georgia, and occur throughout the entire Appalachians. In the east they are sandy, as would be expected in the neighborhood of the coast, and in the west they become finer and finer, until they are actually no longer shales, but limestone, with little clay impurity. This is also a result of the geography of the times, for in the quiet water at a distance from the shore, even fine clayey particles of rock cannot be transported.

The Clinton beds are marked throughout the greater part of their extent by the presence of iron, which in some places is sufficiently concentrated to serve as mines of iron. This is true at Clinton, N. Y., at Birmingham, Ala., and in various intermediate places. For some reason during the time of deposit of these layers, the ocean waters were furnished with considerable iron, some of which was perhaps directly gathered into the iron veins, but most of which was scattered through the accumulating rocks. By later changes this iron has in some places been gathered into veins. As for the source of the iron, no definite statement can be made; but it may have been derived from lavas furnished by volcanic action in the mountains of the east, which were supplying the materials out of which the beds were being constructed.

The next epoch, the Niagara, indicates another change of conditions in New York: for above the shales of the preceding time, occurs a limestone, which in the western part of the state attains a thickness of eighty-five feet. The variation from the shale to the limestone is somewhat gradual in places, though at the Falls the change is abrupt. In fact, the very existence of Niagara depends upon the rapidity of this change from friable shales to the overlying compact limestone (p. 167).

This limestone, resting as it does upon shale, shows a decided change in conditions. For some reason, very probably the deepening of the sea, the waters which had up to that time been depositing clay and sand, derived from the land, were unable to do so longer, and began to build limestone rocks.

Diverging for a moment from New York state, it may be said

that during the Niagara at least a part of New England was beneath the sea. It is possible that at previous times this had also been true, but later changes have so altered the rocks of these states, that their history is difficult to decipher. The condition of New England at this time appears to have been that of mountains of considerable height, penetrated by arms of the sea. One of these arms was the Connecticut valley, which again and again during the development of the country, has been alternately raised above the level of the sea and depressed beneath it.

After the Niagara epoch there occurred a slow change back toward shallow-water conditions, which permitted the deposit of shales upon the limestone of the Niagara. While these rocks (the Onondaga) were being accumulated, the conditions in central New York changed absolutely, so that for a time it was possible for beds of rock-salt and gypsum to be deposited. For some reason, which cannot be stated with definiteness at present, large areas of shallow salt water were subjected to evaporation, so that between the beds of shale, layers of gypsum and salt were gathered. These salt-bearing beds constitute the Salina division of the Onondaga.

It is possible that the accumulation of this salt proves that during the time of its deposit, the climate of central New York was arid, like that of parts of the west at present, and that the region was occupied by an arm of the sea, temporarily separated from the open ocean, as the Caspian is to-day, and as at any time, by slight geological changes, the Mediterranean may come to be. It cannot be said that this is proved, for it is also possible that this part of the state was a great shallow arm of the sea, subjected to evaporation, and so cut off from its supply of pure salt water that salt was precipitated as it is in salt vats. All of these beds are found to be unusually free of fossils. We would expect this to be the case, for in a body of water precipitating salt, life could not exist in abundance. The Onondaga group has a thickness of from three hundred to fourteen hundred feet, and in this there are rock-salt beds whose total thickness in some places is one hundred feet.

These salt-bearing beds are succeeded by impure clayey limestone (the Waterlime). After the deposit of these beds, open-water conditions returned, and then a bed of limestone (the Helderberg) was deposited, in some places three hundred feet thick.

Devonian Geography. — The dividing line between the Silurian and the Devonian is not sharp in New York, and there, as well as in northern Pennsylvania, we find the conditions of the former period extending by slow gradations into those of the latter. There is a change between the limestone of the Helderberg and the next higher sandstone strata (Oriskany), and from this to another bed of limestone (the Corniferous). In some places these changes are abrupt, in others gradual.

The next series of strata deposited in the Devonian, was one of sandstone and shales in the Hamilton epoch. These, as one would expect, are thicker and coarser in the east. Even more markedly is this difference in texture illustrated by the next and uppermost series of Devonian beds (the Portage and Chemung). The conglomerate and sandstone beds existing in the Catskill region, mark the site of the old upper Devonian shore, along the land which extended eastward over New England. From this coarse beach the rocks grade to beds of finer grain, until in western New York they are sandy shales. This difference in place of accumulation is now stamped upon the topography of the state. Because of the hardness of the rocks in this old beach, the Catskill Mountains stand out as bold and prominent peaks, which have resisted the action of post-Devonian denudation, while the plateaus of central and western New York, made at the same time, but of less durable material, have been worn down to the appearance of moderate irregularities.

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Devonian Geography. — The dividing line between the Silurian and the Devonian is not sharp in New York, and there, as well as in northern Pennsylvania, we find the conditions of the former period extending by slow gradations into those of the latter. There is a change between the limestone of the Helderberg and the next higher sandstone strata (Oriskany), and from this to another bed of limestone (the Corniferous). In some places these changes are abrupt, in others gradual.

The next series of strata deposited in the Devonian, was one of sandstone and shales in the Hamilton epoch. These, as one would expect, are thicker and coarser in the east. Even more markedly is this difference in texture illustrated by the next and uppermost series of Devonian beds (the Portage and Chemung). The conglomerate and sandstone beds existing in the Catskill region, mark the site of the old upper Devonian shore, along the land which extended eastward over New England. From this coarse beach the rocks grade to beds of finer grain, until in western New York they are sandy shales. This difference in place of accumulation is now stamped upon the topography of the state. Because of the hardness of the rocks in this old beach, the Catskill Mountains stand out as bold and prominent peaks, which have resisted the action of post-Devonian denudation, while the plateaus of central and western New York, made at the same time, but of less durable material, have been worn down to the appearance of moderate irregularities.

It is such variations as these in the rock record, that have convinced the geologist of the constant variety in the history of the past. Now there is dry land, and then very soon, its place is occupied by the ocean; and again, perhaps after the lapse of some time, there is another change back to the condition of dry land. The sea is now shallow and again deep; or now under the influence of the land, when the deposits are either muddy, sandy, or pebbly, while later the water has become clear, and so free from land sediment that beds of limestone can accumulate. Evidence of constant change, operating slowly and even imperceptibly, is ever seen by the student of the earth's crust. No doubt these same changes are even now in progress; and could we watch them for many centuries, we would find the same variations in the conditions of the present, as are so plainly recorded among the rock leaves of the earth's history.

Carboniferous Geography. — The great Paleozoic sea, in which much sediment derived from the neighboring mountains had been accumulating, was destroyed during the Carboniferous period, and the land east of the Mississippi River was permanently changed to dry land. This elevation accompanied the growth of the Appalachian Mountains. Throughout all the immense ages of the Paleozoic, the bottom of this inland sea was slowly sinking; and then, towards the close of the Carbonifer-

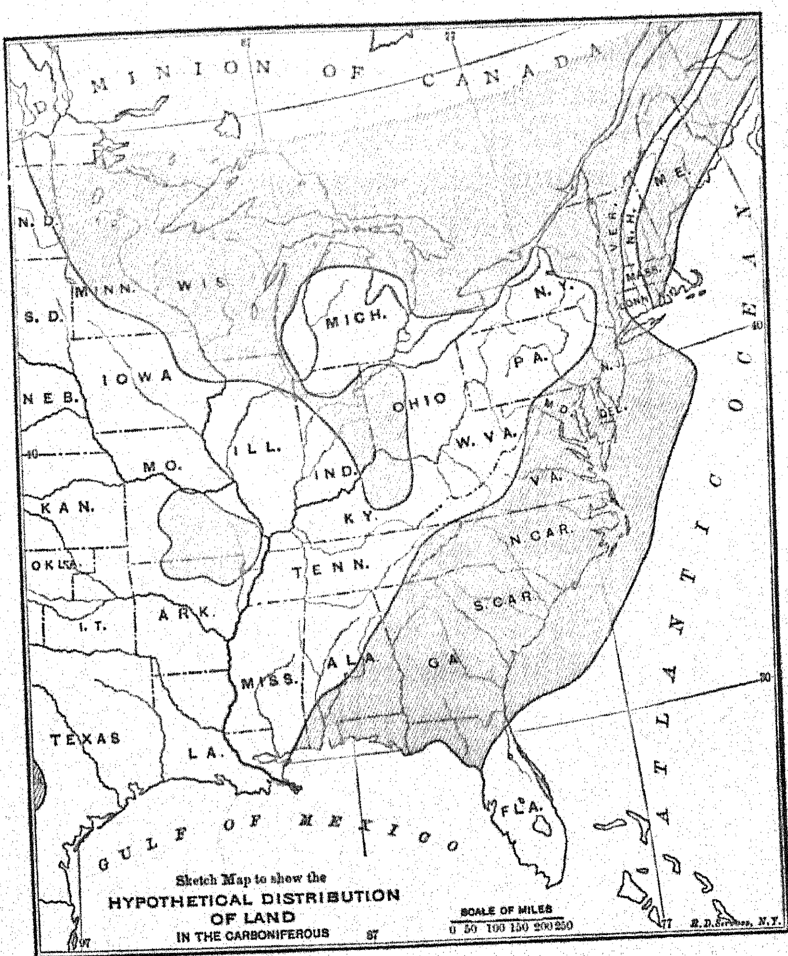
DOMINION OF CANADA
ATLANTIC OCEAN
GULF OF MEXICO
N. D.
S. D.
MINN.
WIS.
MICH.
N. Y.
VER.
N. H.
ME.
MASS.
CONN.
PA.
N. J.
IOWA
NEB.
OHIO
MD.
DEL.
ILL.
IND.
W. VA.
MO.
KAN.
KY.
VA.
N. CAR.
OKLA.
TENN.
S. CAR.
I. T.
ARK.
MISS.
ALA.
GA.
TEXAS
LA.
FLA.
Sketch Map to show the
HYPOTHETICAL DISTRIBUTION
OF LAND
IN THE CARBONIFEROUS
SCALE OF MILES
0 50 100 150 200 250

PLATE 25.

ous, the reverse motion occurred, and it rose above the ocean.

Throughout the earlier part of the Carboniferous, conglomerates, sandstones, and shales continued to be deposited near the eastern shores in Pennsylvania, and the states south of this; but to the westward, in the great Mississippi valley, the sediments were of finer texture. About the middle of the period, the sea shallowed in various places and soon became transformed to marshy lands. The ancient shore-line, now occupied by the Appalachians, was then fringed by extensive marshes; and similar tracts of swampy land existed in Illinois, Iowa, Texas, and other parts of the interior.

On these swampy districts vegetation grew in great abundance. There were veritable jungles with trees of weird form, — gigantic ferns, cicads, lepidodendrons, etc. The climate of the period was equable and the vegetation had a tropical aspect. The atmosphere was humid because of the great extent of water and swamp, and some believe that it contained much more carbonic acid gas than is now present. It is thought by many that the coal-forming vegetation withdrew this gas from the air and accumulated it into beds, so that the atmosphere after the coal period, or Carboniferous, became suitable for the existence of the higher forms of land life. It must be said, however, that this is merely theory, against which facts can be raised.

The vegetation which by its life and death made possible the coal beds that we now find so useful, fell in such a position that it was protected from decay in the air; and after a certain accumulation had been made, was buried beneath layers of sediment, and hence still further protected. Plants that die and drop upon the ground, soon decay and return the greater part of their substance to the air and earth; but in swamps this rapid disintegration is checked by the presence of water and preservative acids, that are generated by the decaying plants. Hence in swamps it is possible for vegetation to accumulate in thick beds, as we may see in any peat bog of the northeastern states (see p. 190).

The fact that coal-forming plants were able to accumulate in considerable thickness, proves that when they fell they dropped into bodies of water. Whether these coal marshes were actually salt or fresh water swamps cannot now be stated. At present but one kind of tree, the mangrove (p. 251), is able to grow with its roots in salt water. This tree, where it exists in tropical lands, forms jungles quite like those which many believe to have existed during the Carboniferous times. It is by no means impossible that the primitive trees of the Carboniferous were able to exist when surrounded by salt water, although the more advanced trees of the present would be destroyed by the presence of salt water about their roots.

It is not necessary to believe that these swamps were salt marshes, for they may have existed on lowland, partly elevated above sea-level, and covered by swamps, similar to the Dismal Swamp of Virginia and North Carolina, and the extensive swamps of Florida.

Whatever the condition of the land on which the plants grew, they existed so near the level of the sea, and upon land so unstable, that every now and then the area they occupied was lowered beneath the sea-level. Among the coal-bearing beds are found layers of coal covered with strata of sandstone, limestone, or clay, in which fossils of ocean animals abound. Hence we have recorded the alternation from swampy conditions to submergence by the ocean. The land was therefore in a very unstable condition, now being above the sea, now beneath it.

By slow transformation these buried beds of vegetable remains have been changed to coal. The volatile substances have disappeared, and the carbon and earthy ash have been left. This product is *bituminous* coal. In some places the metamorphism has gone so far that the purer *anthracite* has been formed. This is especially developed where mountain folding has caused the changes.

This instability of the shallow sea bottom and marginal coast swamps, was accompanied and succeeded by the growth of the Appalachian Mountains. In fact, the unstable sea bottom was a sort of premonition

of the extensive mountain growth which was about to begin. The beaches and off-shore deposits that had been accumulating since the Cambrian, were now involved in a series of folds, and raised into mountains much higher than the present Appalachians. Out of these, later denudation has carved the mountain ridges, at the same time reducing the elevation.

Mountain folding has occurred in the west, but here, as in the preceding ages, the history of the geological development is only obscurely understood. In Texas, Kansas, and other parts of the west, the real coal-forming period of the Carboniferous was succeeded by the Permian division, which in that part of the country was marked by a climate sufficiently dry for the development of dead seas.

The coal period of this section had been one of equable, moist climate. It was succeeded by aridity, and the most reasonable explanation of this is the development of western mountains, which rose to a sufficient height to cut off the west wind, and transform the region to a condition of dryness, just as the Sierra Nevada and Rocky Mountains cause an arid climate in the great western region of to-day. During this arid part of the Carboniferous, extensive salt lakes existed in various parts of the west; and in the bottom of these great inland seas, beds of salt and gypsum were deposited. Both in Kansas and Texas, man is now utilizing these as a source of salt, by penetrating the earth with borings and bringing the salt to the surface.

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CHAPTER XXV

MESOZOIC AND CENOZOIC GEOGRAPHY OF THE UNITED STATES

Juratrias Geography. — In Europe this part of the Mesozoic is much better developed and studied than in America; but rocks of these ages are found in the extreme east and the Far West. The record which they have yielded is extremely incomplete and unsatisfactory. However, even this fragmentary record is sufficient to throw some light upon the conditions of the times.

The general absence of Juratrias rocks seems to show that in America, this age was a time of prevailing land conditions. Had the sea been extensive, more deposits should have been left. We know that there were mountains in the east, and that to them had been added the Appalachian chain, while extensive plains stretched from their base at least as far west as the Mississippi River. It also seems certain that the Canadian area was mainly land. With this increase in dry land, the climate changed from the

uniform, equable condition of the Carboniferous, to a varied climate, in which some sections were warm, some cold, some moist, and some dry.

It has been thought that evidences of glaciers have been found in the rocks of this time; and with the development of lofty mountain ranges, which occurred at the close of the preceding period, it would not be surprising if this were true. There is a wonderfully close relation between climate and land topography. During the early Carboniferous, the sea occupied extensive areas; and the land of that time had been reduced in elevation through long periods of denudation. With such geographic conditions, there was little cause for local variation in climate; but after the growth of mountains, and the reduction of sea area, such variations would certainly be expected.

In the east, Triassic rocks are found in various places from North Carolina to the Gulf of St. Lawrence. They are mostly sandstones, colored reddish or brownish, and occurring in limited areas. In fact, many of them bear distinct evidence that they were formed in bays, enclosed within steeply rising walls, just as sediments are now gathering in the Bay of Fundy. Such a bay existed in the Connecticut valley, which it will be remembered was partly occupied by the ocean during the Devonian. Hence we conclude that at this time the eastern coast was a highland region, doubtless indented in a manner similar to that of the present coast of Europe and America.

These rocks also bear evidence of still later moun-

tain growth in the east; for although they were deposited horizontally in the sea, or in bays, they are now tilted, and in some places considerably broken. Among them are found volcanic rocks, — black trap, or diabase. This class of lava is found in the Triassic strata from Nova Scotia to Pennsylvania, and even south of this. Throughout this entire area, the trap is of the same nature. It represents the last period of volcanic eruption in the history of the eastern part of this country.

The lava flows from this system of volcanoes, now forming the prominent hills of Cape Blomidon, Nova Scotia, the Hanging Hills of Meriden, Conn., Mounts Tom and Holyoke, in Massachusetts, the East and West Rocks of New Haven, Conn., the Palisades of the Hudson, and the hills near Paterson and Orange, N. J.

In the Far West, the close of the Juratrias was marked by an extensive mountain growth, similar to that of the Appalachians. During this time the Sierra Nevada were elevated to a great height. Among the strata of these mountains are found highly altered slates of Juratrias age. These were therefore deposited at that time, and have since been raised, folded, and changed from clay sediment to hard slate rocks. Previous to this time the history of the Sierra had been complex, and their later development is also complicated.

The alteration which has occurred among the rocks of these mountains, has caused the accumulation of very important deposits of minerals. Associated with the slates are veins of quartz, in which gold occurs in considerable abundance. These gold-bearing quartz veins are now being worked; and gravels, accumulated in stream beds as a result of the disintegration of the slate and quartz, have furnished large stores of this precious metal. It is not certain whether the gold was originally disseminated through the clay beds, and then gathered into veins, or whether it has come from some lower source in the earth, and has filled the veins.

Cretaceous Geography. — The prevailing land condition of the Juratrias was gradually succeeded, during the Cretaceous period, by the invasion of a part of the country by the sea (Fig. 262). The Atlantic Ocean extended over the eastern part of the present seaboard states south of New England. Nearly the whole of these states, from New Jersey to Georgia, were covered by the sea; Florida and the greater part of Alabama and Mississippi were also submerged. From the Gulf shore northward, a branch of the sea extended apparently as far as the Arctic circle, and the states between the Mississippi River and the Rocky Mountains were covered, while the sea invaded a considerable portion of the Cordilleran region.

In some places this sea was very deep, and conditions existed like those now favorable to the accumulation of Globigerina ooze in the deep sea. Chalk beds were then formed in Texas, Iowa, and other places.

The climate of the Cretaceous seems to have been more uniform and warmer than that of the preceding period, and plants and animals now found in temperate regions, then lived in the Arctic.

In the east, slight changes occurred at the close of

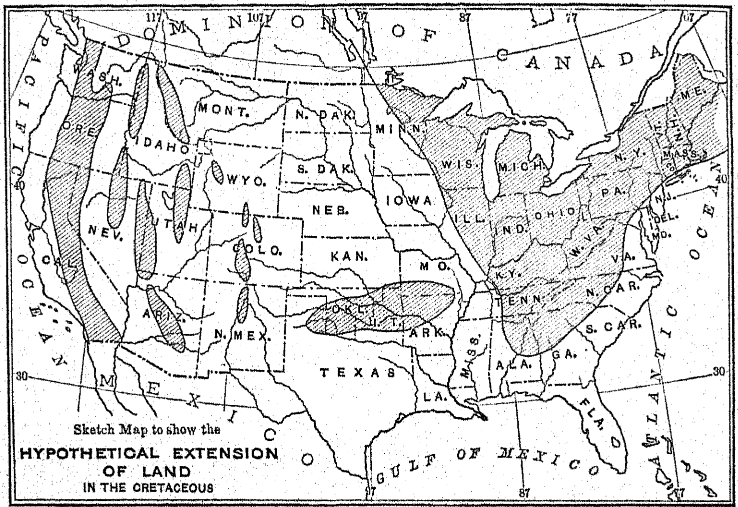

FIG. 262.

Hypothetical distribution of land shown by shading.

the Cretaceous; but in the west, the close of the period was marked by a revolution in the geography. Much of the Cordilleran region was raised above the sea, and the lofty mountains, which were mainly developed in the next period, in this one began to rise. As in the Carboniferous, when the Appalachians

were formed, the mountain elevation was accompanied by an uplift of plateau and neighboring plain. This mountain formation involved the entire western part of the Mississippi valley, and raised above the sea the old ocean bottom of Cretaceous times.

Accompanying the growth of these western mountains, there was a notable development of volcanoes throughout the west, from Canada to Mexico. These continued to erupt throughout the next period; and as a result of their action, the Cordilleras of the west, and their included plateaus, are the site of remains of volcanic cones and of extensive lava flows (see pp. 330 and 350).

The mountains rising above the sea, at first transformed the west into a mountainous mass of land, with intermediate arms of the sea, somewhat like the present condition of the eastern coast of Asia. Further development of the mountains cut off these arms, and gradually transformed them to inland seas, at first like the Mediterranean, Black, and Caspian seas, and then like our Great Lakes.

It is interesting to note that the great Mississippi valley, which now forms such an important feature in the geography of the country, had its position practically determined in the very earliest geological ages. Bounded on three sides by mountain masses, it was at first all sea; then as these mountains developed, and the sea bottom was transformed to dry land, the central part of the basin still remained lowland, into which

the water from either side was drained. This lowland condition in the centre, was the result of the fact that the mountain uplift raised the land near the mountains higher than that far removed from them. Hence a trough was constructed, sloping down to the Mississippi valley, from the base of the mountains on either side. Other valleys, like the St. Lawrence, seem

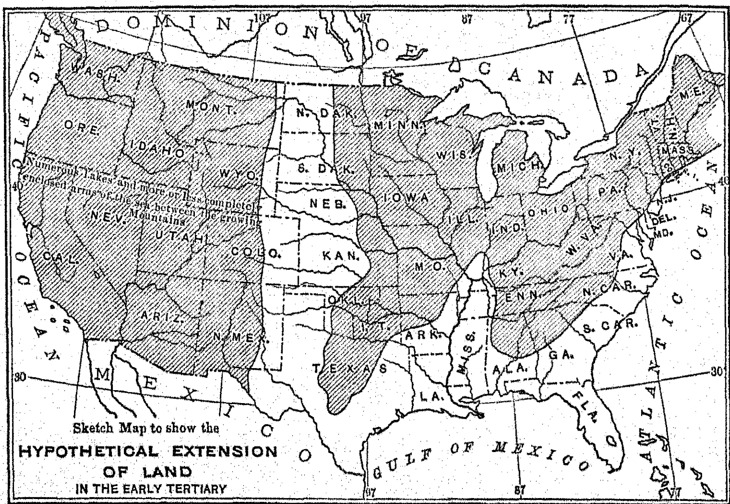

FIG. 263.

Shading indicates land.

also to have been determined in earlier ages, and to have maintained their approximate position, with many variations, throughout geological times.

Eocene and Neocene (Tertiary) Geography. — These periods, which are often considered to be parts of the Tertiary, continued the record of development down nearly to the present time. In the west, mountain

growth and volcanic action continued, and the land rose higher and higher, while lakes that had been seas during the Cretaceous, were completely enclosed by mountain barriers. During this time the west was the seat of many extensive lakes, in which beds of sediment were accumulated. In these, records of animal and plant life of the times were preserved, so that from them we gain a rather clear knowledge of the life that then peopled the earth. Some of these lake beds, which were of course deposited in horizontal layers, are now found folded and tilted in mountain ranges, of which they form a part. Hence we may be certain, that after the lakes were formed, mountain development tilted and drained them, and built their beds into folds.

It is probable that this series of changes represents the normal mode of development of mountains in the sea. At first a chain, like that of the Aleutian islands, rises out of the water as a series of peaks. The next stage finds the islands more numerous and larger, as in the case of Japan, while between the folds there are arms of the sea enclosed, as we find in the East Indies. The next stage in the development has transformed those open arms of the ocean to nearly closed seas, like the Mediterranean. A very slight additional change would cut off the sea entirely, elevate the arm above sea-level, and change it to a fresh-water lake.

The Tertiary volcanoes were remarkably abundant and active. Thousands of cones, in all stages of destruction, are now seen dotting the plateaus and mountains of the west (p. 330), and scores of thousands of

square miles of western plateau are covered with the lava which has been erupted from these vents.

In the eastern part of the country, the seaboard states were still partly below the sea-level at the beginning of the Tertiary period. As a result of this, beds of marine deposits were laid down over the eastern border of the states south of New Jersey. Long-continued denudation had lowered the remaining part of the eastern states to a lowland condition. Even the mountains were greatly reduced in elevation. Then followed an uplift, which brought not only the eastern part of the country above sea-level, but also elevated the sea bottom, which lay off the shore, to a condition of dry land. This uplift raised the land and sea bottom to a height, which in New England was certainly not less than one thousand feet above the present.

The evidence of this is of two kinds. In the first place, the coast of New England and of Canada is entered by the sea in the form of numerous bays and fjords. These bays, such as the St. Lawrence, are seen to be perfect river valleys whose ends are partly beneath the sea. Such is the case, for instance, with the Hudson, Delaware, Chesapeake, and the thousands of smaller bays upon the eastern coast. The second evidence is found upon the bottom of the sea. Soundings made there have revealed the fact that off the mouths of some rivers, such as the St. Lawrence and Hudson, there are distinct channels cut into the bottom, and extending from the present mouth of the river to the edge of the shelf which borders the continent (Fig. 181). These have every appearance of being river valleys; and if so, they must have

been formed as such valleys are known to be, by action in the air. Granting this, then the conclusion must be that these parts of the sea bottom, whose depth in places is as great as one thousand feet below sea-level, must once have been exposed to the air.

After this there came another depression, in which a part of the present coast-line, especially of the southern states, was lowered below sea-level. This involved particularly the Florida peninsula and the Gulf coast, where an arm of the Gulf invaded the Mississippi valley for a distance of several hundred miles.

The climate of the Tertiary period was warm. It was so much more moderate than the present, that plants, like the willow, maple, and other trees characteristic of the temperate zone, lived on the seashore as far north as Arctic exploration has gone. Fossils of these plants may be taken out of the rocks from beneath permanent cliffs of ice. Hence during this period, a temperate climate existed where now permanent ice covers the land. Toward the close of the Tertiary, and accompanying the great uplift that has just been described, there came a change in climate, from the warm, equable condition of the Tertiary, to cold Arctic conditions. This continued into the next era, the Quaternary, and developed into the Glacial period. This change in climate not only accompanied the uplift, but perhaps was caused by it.

Quaternary Geography. — In the eastern part of the United States, the geographic conditions of the Quaternary were not greatly different from those of the present. Some small portions of the seaboard states were submerged; and gradually, as the Quaternary continued, these rose above the sea until the present boundary of the country was reached (p. 298).

In the west, however, mountain growth continued, and with it volcanic action. The last of the western mountains to form were the Coast Ranges, which are probably even now in process of uplift, although they have passed the time of maximum growth. In various parts of the plateau region, other mountain chains were formed, and here also, in some places the mountain growth seems to be still, though slowly, in progress.

During the Tertiary, many lakes of large size covered parts of the west. Some of these were destroyed by filling with sediment, others by having their barriers cut down by the streams that flowed out of them, and still others were drained by changes in the level of the land, which so tilted them that the water was spilled out. Some of these basins, formed during the progress of the Cretaceous, Tertiary, and Quaternary mountain growth, still exist in the plateau and mountain country. Of these very few now contain water, and most that do are occupied by shallow salt pools in the lowest parts of the basins.

This arid condition which now forbids the filling of the lake basins with water, has replaced more moist conditions in Quaternary times. At first, in the early Quaternary or later Tertiary times, these basins were dry, as at present. Then the waters rose as the climate became more moist. This was followed by another period of aridity, when the basins lost much, if not all, of their water supply. Following this came another period of moisture, when fresh-water lakes were again present; and now we find the basins again dry.

These changes in lake history, and hence also in climatic conditions, are definitely recorded on the margins of many of the lake basins of the west, in the form of ancient beaches and wave-cut cliffs. These records are so clear that even the most uneducated must notice them.

The Glacial Period.[1] — *Cause.* The change in climate, from the warmth of early Tertiary to the Arctic conditions at its close, finally succeeded in enwrapping in a great ice sheet, both northeastern North America and northwestern Europe (Fig. 264). There seems to have been little or no ice in Asia, and very little in northwestern America. The explanation for this change in climate has been thought by some to be astronomical. Through changes in the relative position of sun and earth, there is a variation in the distribution of heat

[1] See Chapter XI., Glaciers.

throughout the seasons. This variation occurs at long intervals of time, and the suggestion is, that the differences were at this time sufficient to cause the Glacial period. There are various objections to this explanation, perhaps the most potent of which is, that the Glacial period affected the North Atlantic basin, rather than

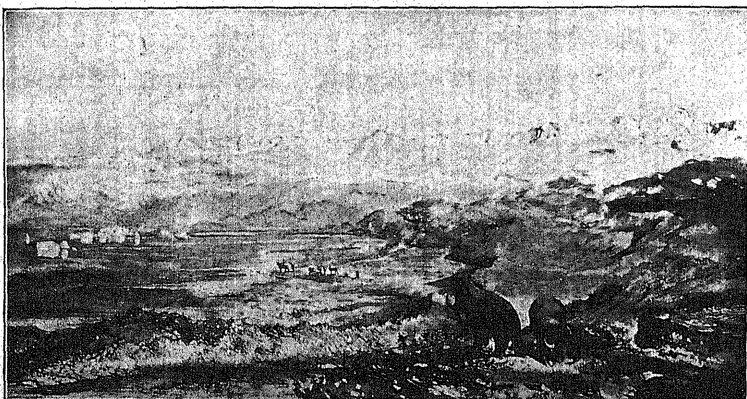

FIG. 264.

Ideal landscape in the Ice Age. (After Haushofer.)

the entire northern hemisphere. Had the cause been mainly or purely astronomical, it should have been more widespread.[1]

While it is *possible* that those astronomical causes may have *aided* in the change of climate, it seems

[1] This theory is known as Croll's hypothesis, and the astronomical changes in question are those resulting from the precession of the equinoxes, and the variation in the eccentricity of the earth's orbit, which will be found explained in some astronomies, and in Croll's *Climate and Time*.

probable that geographic changes furnished the main reason for the coming of the period of cold. An elevation of the land, such as that which occurred just before the Glacial period, would produce a profound influence upon the climate. The additional land area, resulting from the elevation of parts of the sea bottom, may also have interfered with the normal oceanic circulation of Tertiary and present times. The withdrawal, for any reason, of a part of the warmth brought to the North Atlantic by the Gulf Stream, would lower the mean annual temperature of this part of the world very appreciably. While it seems more probable that some such geographic explanation as this is the true one for the Glacial period, it must be admitted that since so many uncertain factors are involved, the best we can do at present is to offer theory.

Time Occupied. Not only are we unable to tell why the glaciers came, but we are also unable to state when they began, and how long they remained. Geological studies do not in any case give us a basis for an estimate of time in years. The year is entirely too minute a unit, and there are many variable and uncertain elements to be considered. However, the amount of work performed by the glacier, proves that it covered the land for a long period of time, perhaps for several scores of thousands of years, and some believe hundreds of thousands.

Concerning the time of disappearance there is somewhat better evidence. Niagara River did not commence to cut its gorge until the ice had withdrawn from the site of the river. Therefore, the

time needed for the construction of Niagara gorge represents the length of time since the ice left. If we should assume that the present rate of retreat of the falls is a fair average of the past rate, it would give as a result, between 5000 and 10,000 years as the time that has elapsed since the Glacial period. Here, however, there are elements of uncertainty; and the estimates of different students vary between 5000 and 30,000 years, though many are inclined rather toward the smaller than the larger figure. Studies of the gorge below the falls of St. Anthony, in Minnesota, furnish the same result, and point toward 10,000 years as the most probable length of time. Whichever of these estimates may be taken, the Glacial period is a recent one in geological time.

Work Done. Because of the recency of the glacial action, marked signs of its presence and work have been left; and since these signs are to be found on every hand, in the northern and eastern parts of the country, it is well to give a little more space to this period than to those which have preceded.

At first, all the land north of the boundary which is marked on the map (Fig. 265) was transformed to a great monotonous sheet of ice, like that which now covers Greenland (Fig. 118). In this there was a slow movement outward from the centre, which in the east American ice sheet was over Labrador and Hudson's Bay. As in Greenland this movement was irresistible, though slow, and overran all land, both mountain top and valley bottom. The cause for this movement may have been partly the greater elevation of the land in

the central region, and partly the result of the greater accumulation of ice in this centre. Ice may be made to flow in a manner somewhat like that of wax; and if accumulated to a great depth in one place, this flowage may cause an outward movement from the place of accumulation. It is as though it were squeezed outward by the great pressure of the overlying mass.

FIG. 265.

Ideal map showing extension of the ice sheets in North America (Chamberlin).

Before the ice came, the surface of the country was carved into hills and valleys, very much as it is now, in the region south of the glaciated land. The rocks of this pre-glacial land had been decayed, and upon them soil had gathered. Moving over this surface, and grinding it as it passed, the ice swept away this loose material, and even dug down into the rock itself. Hills were thus planed down somewhat, and valleys deepened; but the changes of this nature were not sufficient to erase, or even greatly modify, the larger features of the land.

Deposits. Moving forward, the ice dragged these rock fragments along, mostly beneath it as a ground moraine, but also in slight part within it. Excepting at its margin no morainal matter was carried on the back of the glacier, because no land projected above the surface. The ice was as clean and free from rock materials as the ice cap of Greenland. Even the highest mountains were covered (the Adirondacks of New York, the Green Mountains of Vermont, and the White Mountains of New Hampshire, for instance), and therefore the ice sheet was in places no less than a mile in depth. Where the glacial front stood in the sea, as it did east and southeast of New England, as it advanced it disappeared in icebergs, which floated away in the water; but where the termination was on the land, it extended to the point where melting exceeded supply, and there it ended in running water.

Along this land margin interesting results were brought about. As the water flowed from the ice, it sometimes formed marginal lakes where the glacier wall served to dam back the north-flowing streams; and in these lakes, beds of sediment were accumulated. In other places the streams emerging from the ice front crossed the pre-glacial divides, and cut them lower, so that when the ice withdrew from the land, some streams, whose pre-glacial course was northerly, were enabled to flow southward over their old divides, being then reversed. A very considerable part of the headwaters of the Alleghany River in New York and Pennsyl-

vania, have been added to this river by the reversal of north-flowing streams.

Rivers that emerged from the ice into valleys that sloped toward the south, poured into them, not only quantities of water, but also a great amount of sediment, which had been ground from the rocks during the passage of the ice over them. In this way many valleys were partly filled with sediment, which the streams could not carry far from the ice front. By this means terraces were constructed, and broad plains of stratified gravel were built.

All of these features may be seen on the land occupied by the margin of this ancient glacier; but when the ice finally withdrew by melting, the line of action of these ice agents was gradually removed to more and more northerly points. This withdrawal of the ice was rapid in the main, but was accompanied by numerous halts, during which, for periods of time variable in length, the ice front stood at various points north of its southernmost limit. Whenever it stood for a sufficiently long time, the material brought to the front was gathered into marginal deposits, known as *terminal moraines* (Figs. 266 and 267). The southernmost of these is along the line marked upon the map (Fig. 265) as the southernmost limit of the ice advance; and north of this are numerous other and usually smaller moraines.

The terminal moraine represents not merely the accumulation of debris brought and dropped by the ice, but also certain deposits of this debris which have been

modified by the action of water furnished by the ice melting. Its resultant *structure* therefore is complex, in some places being a jumble of pebbles and clay, known as bowlder clay, while perhaps even in the same hill, are found layers of sand and gravel assorted and stratified. The *surface outline* of the

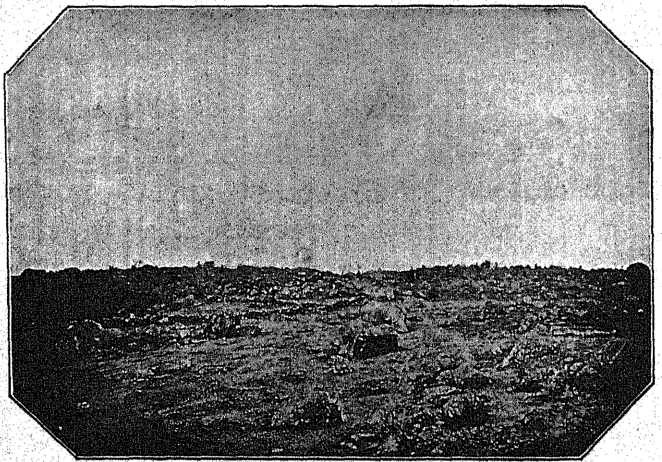

FIG. 266.

Very rocky terminal moraine, Cape Ann, Mass.

moraine is also irregular, and the typical morainal topography is that of hummocky and tumultuous hills (Fig. 267). It is one of the most irregular surfaces, in small details, that is known in this country.

Lakes Formed. As the ice withdrew, in the course of time the valley of the Great Lakes became uncovered; but before the

valley of the St. Lawrence was opened, parts of the basin of this river, not now occupied by lake water, were drowned by the marginal lakes. The normal St. Lawrence channel being forbidden, other outlets were found; one of these was past Chicago, another by Fort Wayne, Ind., and still a third through the Mohawk in New York. As the ice withdrew, and these outlets were one by one revealed, the overflow of the Great Lakes successively changed, until finally, the present channel past the Thousand Islands was

Fig. 267.

Surface of the terminal moraine near Ithaca, N. Y.

assumed for the outlet. This complex history of the Great Lakes is clearly recorded in the ancient beaches which now exist upon the land on either side (Fig. 177), and at various elevations above the present lake waters. During this time of withdrawal of the glaciers, other temporary great lakes were caused in the valleys of north-flowing streams, the most notable of which was an immense lake formed in the broad valley of the Red River of the North.

Changes Caused. Since the glacier transported much rock material in the form of a ground moraine, as it retreated from place to place, and finally disappeared by melting, the greater part of this rock load was left wherever it happened at the time to be. So the surface of the country once covered by ice, is now strewn over with a sheet of ground moraine, called *till* or *bowlder clay* (Fig. 114), which forms the chief soil of glaciated regions. In some places this soil is so thin that the rocks are barely covered, and upon some mountains not even the thinnest film was left. On the other extreme, there are some parts of the country in which the glacial soil reaches a depth of 200 or 300 feet.

By this and other glacial accumulations, many changes in the land surface have been introduced. Rivers have been extensively dammed to form lakes, and others turned from their ancient valleys, either entirely out of their course, or to one side of their old channel. As a result of this, in the process of cutting new valleys, gorges have been carved and waterfalls produced (Figs. 81 and 82, and Plate 7). There have been great changes in *detail* of surface outline, though the *prominent* features of pre-glacial times have not been changed.

The Glacial Theory. No mention can be made of the various peculiar forms assumed by the till, and the deposits formed in water furnished by ice melting, though there are many interesting

varieties of these deposits. However, the subject should not be left without stating the main reasons for the conclusion that the ice sheet really did come, and how the facts stated above prove it. There is a belt, extending up hill and down, and stretching across the country in a general east and west direction, north of which the country presents entirely different conditions from those to the south. North of this area, which is that of the terminal moraine, there is an abundance of lakes, gorges, and waterfalls, while south of it they are uncommon.

Also, the soil is not due to rock decay, as it is to the south, but is made of clay, mixed with bowlders and pebbles, whose home and origin is north of their present position, and sometimes hundreds of miles to the north. Something has carried these, and of all the agencies known, ice is the only one that is capable of transporting large bowlders for great distances and depositing them surrounded by beds of clay. Moreover, the bowlders show signs of grinding, for the clay in which they are bedded is a true rock flour, and the pebbles are scratched and smoothed (Fig. 113). The bed rock over which the materials have been carried is also polished, grooved, and striated by the scouring it has received (Fig. 268). These striæ point toward the direction from which the bowlders have been brought.

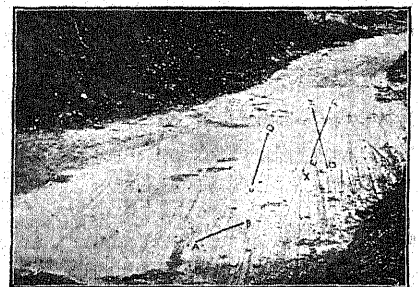

FIG. 268.

Glacial striæ on rock over which glacier has moved.

Long before the glacial theory was proposed to account for these peculiarities, it was thought that the surface of the land had been covered by immense floods of water, which had deluged even the highest mountains, and strewn the surface with the glacial and other deposits. It was believed that these floods had

broken up the ice of Arctic regions, and transported materials from northern points by means of the icebergs thus derived. This theory failed to account for many of the phenomena, and was very unsatisfactory, even before the glacial theory was suggested. Louis Agassiz, studying the valleys of the Swiss Alps, saw glacial deposits and signs of glacial action below the terminus of the Alpine glaciers (p. 211). Upon this evidence he concluded that at one time glaciers had extended further down the valleys than at present. Coming to America he saw that the soils and surface feature of New England resembled those in the Alpine valleys, which had once been glaciated. Upon this evidence he proposed the glacial theory, now so universally accepted.

This explanation alone, of those that have been suggested, will account for the phenomena. There are many things connected with the deposits which cannot possibly be explained by the effects of water, the most notable of which is the fact that the terminus of the glacial deposits is a purely arbitrary belt, extending westward across the country, and not governed by irregularities of topography. Why should the ocean floods stop at such a belt, sweeping over the country on the northern side and producing no effect to the south?

Conclusion. The Glacial period influenced this country so recently that its effects are very noticeable. The ice sheet has withdrawn from Labrador even more recently, and indeed, the surface of some of the rocks of that peninsula have been so little changed since the Glacial period, that the striæ and grooves formed by the ice have not been decayed, even from the surface of rocks that are exposed to the air. In Greenland the glacier still remains, but it is withdrawing at a notably

rapid rate. The climate there is even now in process of change. What its outcome will be no one can tell; but surely at the present time the climate of the northern hemisphere shows signs of increasing moderateness. Possibly then, the time may come when, as in the Tertiary period, life can extend its zone of occupation further and further north following in the wake of the retreating ice sheets.

The Glacial period has produced effects of the utmost importance to man. The ice has occupied a large part of the world in which the later history of mankind has been enacted. Northwestern Europe and northeastern America are the seats of two important civilizations, and the changes caused by the ice, and accompanying it, have been among the most notable of the influences upon which the development has taken place. The very soil that he tills, the harbors of the coasts, the water power of the rivers, and much of the scenery of the land, have resulted from the conditions accompanying ice occupation and withdrawal. Man is dependent upon the earth, and everywhere we see close relation between his progress and the geological conditions; but in no instance is this more strikingly shown than in the case of that latest great change, the Glacial period.

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